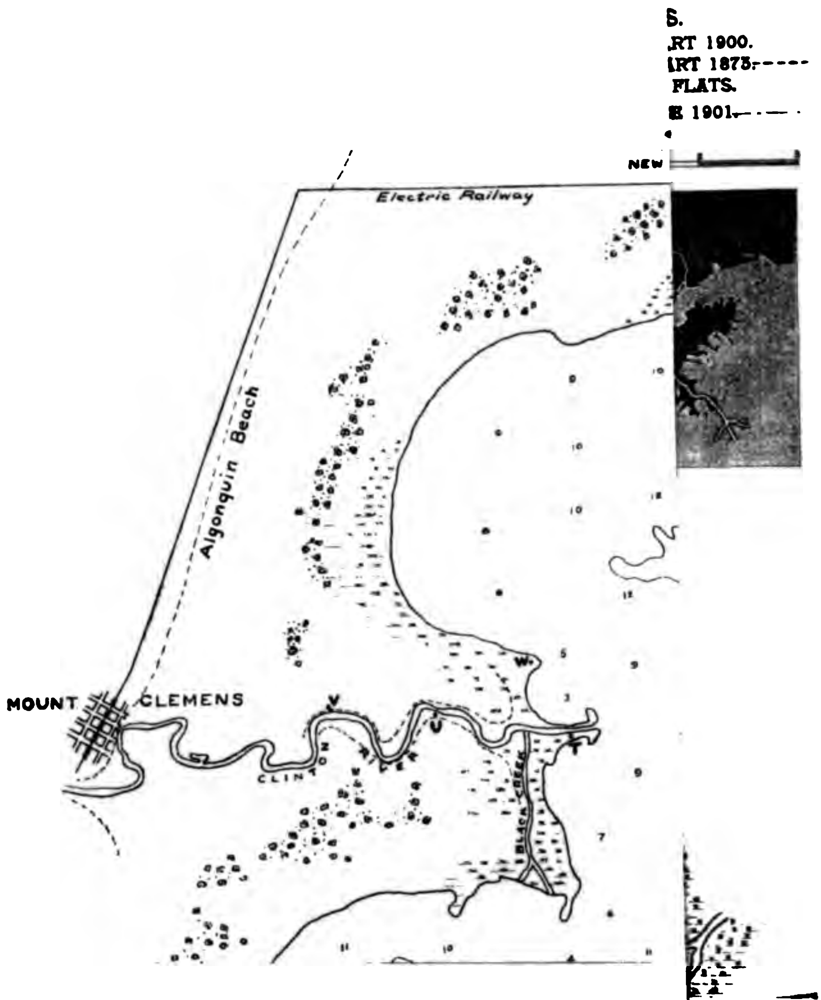
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To be inserted in Volume IX.

GEOLOGICAL SURVEY OF

MICHIGAN

1903-1904

VOL. IX

PART I. ST. CLAIR DELTA, L. J. COLE
PART II. GYPSUM, G. P. GRIMSLEY

GEOLOGICAL SURVEY OF MICHIGAN

ALFRED C. LANE, STATE GEOLOGIST

VOL. IX

PART I

THE DELTA

OF THE

ST. CLAIR RIVER

BY

LEON J. COLE

ACCOMPANIED BY FOUR PLATES

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1903

OFFICE OF THE STATE GEOLOGICAL SURVEY,
LANSING, MICH., September 10, 1903,

To the Honorable, the Board of Geological Survey of Michigan:

HON. A. T. BLISS, *Governor and President of the Board.*
HON. L. L. WRIGHT, *President of the Board of Education.*
HON. DELOS FALL, *Superintendent of Public Instruction and Secretary of the Board.*

GENTLEMEN—Herewith I transmit as Part I, the first part of Vol. IX, a report containing the results of examination of the Delta of the St. Clair River, known as St. Clair Flats, prepared by Leon J. Cole. At the time, Mr. Cole, now assistant at Harvard University was a student of Prof. I. C. Russell, who suggested the report. Prof. Russell was interested in the exceptional fact of the formation of so extensive a delta from a river which is the outlet of a large lake, and in recommending to your Board to defray the field expenses of the same, I had hoped that information of value to the State would result, as to the rate of growth of the delta correlative to the erosion of the shore north of Pt. Huron which we have recently studied. Although the earlier maps do not prove to be accurate enough to give as much as I had hoped, yet the information gathered is desired at once by the Attorney General's office, and I therefore recommend its prompt publication.

With great respect I am your obedient servant,

ALFRED C. LANE,
State Geologist.

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ERRATA.

Herson Island is thus spelled on the Farmer map of 1838 and the Lake Survey map. Recently in the Farmer map of 1901, the Rand McNally maps, the Bartholemew survey map, the Bridgman maps, etc., it is more commonly spelled Harsen, but without adequate reason for the change that I have discovered.

In correcting proof of the maps Mr. Cole writes:

"It was found very difficult to make direct comparison of the State Survey sheets with those of the Lake Survey, for while the latter give only the main contours accurately, and only approximate the shapes of the smaller islands, cutting off points and leaving out channels—the former on the other hand, gives these things in detail, and since it was impossible to get all in when the thing was so much reduced it became a problem as to where to draw the line—literally as well as figuratively.

Again I know from my familiarity with the place, many places where the Lake Survey has indicated as land, what the State Survey has rightly put down as rushes. Refer, for instance, to the lower end of the Chenal About Rond. Similar cases are numerous—especially where the Lake Survey gives islands which the State Survey does not give at all."

INTRODUCTION.

BY A. C. LANE.

From the study of the St. Clair delta by Mr. Cole which is given below, it is apparent that it is quite comparable to other deltas, especially of fine grained deposits. It is apparent from his drawings, and as one sails over it, that the bulk of the material is extremely fine mud. In that respect and in all respects it resembles very closely some of the salt water marshes of the Atlantic coast with these two exceptions; that since the water is not salt vegetation can infringe upon it more easily and that the tidal movement or variation in water level is neither so great nor so regular.

In its growth it resembles any typical delta and I have placed in one corner of plate 1, a little sketch of the Mississippi for comparison, reproduced from Fig. 942 of Dana's Geology. In any such delta, as in the flood plain of a stream generally, the deposits beneath the channel and alongside it are coarser and tend to be more rapid than those farther from it, being composed of sand which may be rolled along the bottom or brought down in times of flood in the extra strong current. The power of transport of different velocities of streams is given by Dana as follows:—

Velocity in miles per hour.	Size of material.
$\frac{1}{6}$	Fine clay, silt and mud.
$\frac{1}{3}$	Clay.
$\frac{2}{3}$	Sand.
$1\frac{3}{8}$	Gravel stones the size of an egg.
$2\frac{3}{4}$	Loose stones.
4	Flat stones.

The current of the river varies as Mr. Cole has stated, from $4\frac{1}{2}$ miles an hour down; the channels of the stream retain, however, considerable current under normal conditions through the delta. The current of the North channel is said to be $2\frac{1}{2}$ miles an hour. Of course the current there will depend somewhat upon the level of Lake St. Clair, and winds from the south raising that level will tend to check them while those from the north which, as Mr. Cole has remarked, are associated with roily water in Lake Huron and the discharge of sediment from it will lower the level

of Lake St. Clair. As in the Mississippi also, and as Mr. Cole has remarked, there is most rapid deposition directly adjacent to these channels.

There are five different methods by which the land surface of the delta may be assumed to gain upon the water. In the first place there is the deposition of material brought down in times of extra high and roily water. This of course must deposit where the current is most rapidly checked. Now the waters leaving the main channel and filtering through the circumambient growth of rushes have their velocity at once very markedly checked and deposit a very large amount of their load in the banks or levees directly along the river. Secondly, the same growth will tend to strain and filter out floating driftwood from such debris. Thirdly, the vegetation adjacent to the channel has more than its share of air and sunlight and will receive more of the fertilizing mud. In consequence its accumulation by growth and decay upon the spot will be more rapid. The above causes of growth apply to all deltas, and cause growth which is more rapid along the lines of the main channels. There are two further causes of growth which apply to this delta, though not to all, and which would produce a more general advance of the line of the land. For in the fourth place, as Mr. Cole has pointed out, according to the observations of G. K. Gilbert,* the whole land area of the Great Lakes basin is being tilted in the direction north 27 degrees east, at the rate of about .04 of a foot per 1,000 years per 10 miles, the result being that the streams upon the southwest side of the Great Lakes have dead water at their mouths, while on the northeast side they have a rapid current and furnish water powers. As to the various channels through the delta, though Mr. Cole correctly says that there would be a tendency to keep a swift current through the delta owing to the grading up of the channels by the material brought down, yet if the tilting were the other way, inasmuch as the whole difference of the level of the lakes Huron and St. Clair is only about 5 feet, it is probable that the flow would not have been so rapid as we find it. Let us see what the tilting would amount to in the case before us, remembering however, that Gilbert's figures are only approximate and we have no assurance that they have lasted at that rate more than 30 odd years which the measurements cover. The front of the delta is about 6 feet under water and lies pretty close to the south end of the U. S. Ship Canal, for it will be readily noticed upon inspection of the chart of Lake St. Clair issued by the U. S. corps of engineers in 1902, that while it is even a mile or more, sometimes several miles from the point where they draw the land line to the six foot line, the drop thence to 13 to 15 feet of water is quite rapid.

*See the report on Huron County, Vol. VII, part 1, page 36. The tilting with the correction there made is .037 feet per mile in 10,000 years.

The front of the delta is thus fairly well marked, and the thickness of the delta deposit to be inferred corresponds quite well to the results of Mr. Cole's borings. From the front of the delta to the head of the delta, as described by Mr. Cole, where the elevation of the delta surface is some 6 feet above the river level along the same line is about 14.6 miles. The slope of the delta surface is therefore some 12 feet in 14.66 miles, or about a foot (.975 ft.) to the mile. To convert the slope of the delta from the lake level slope to its present slope would require something over 20,000 years, but as a certain part of the slope must be due, as Mr. Cole has suggested, to the slope of the delta growth, and the remaining part only to the tilting, this is a maximum which the age of the delta cannot exceed, unless indeed the rate of tilting has been slower than at present. It would seem more likely that it would be more rapid after the ice age than later.

We assume as an average distance of the delta from the axis of the tilting at the head of the Detroit River about 20 miles. The delta would then tend to rise in the neighborhood of Tashmoo Park about .08 of a foot per 1,000 years which would mean about 5,120 feet advance of the delta front in 1,000 years or 256 feet in 50 years.

The fifth cause of advance of the land line is the cutting down of the outlet of the Detroit River and the consequent lowering of the Lake St. Clair level. At present the policy is in improving the Detroit River to keep the cross section and the carrying capacity of the river as a whole the same, but it may be doubted if in the earlier improvements they kept sufficiently in mind the fact that the effect of deepening Detroit River without filling in the same section in lowering the lake level would be much greater on the small lake than on a large lake like Lake Huron. The St. Clair River has been deepened near the outlet but considering its length, the size of the reservoir behind and the small amount of total descent, it is doubtful whether this deepening has made any change in the regime of the Great Lake System appreciable even in the remotest degree.

Thus all geological indications are that the delta is growing and a land advance of something like 5 feet per year may not be far from the truth as an average, but the growth is undoubtedly more rapid near the channel. The actual state of the water level is however, as Mr. Cole remarked, very variable. When I visited the same on September 1, 1903, the water level was obviously distinctly higher than normal as judged by the vegetation. This, as Mr. Cole has remarked, is a quite sensitive index to the condition. Besides the regular algæ such plants as the bulrush (*Scirpus lacustris*) occur in quite deep water. Some I pulled were in 40 inches of water. They may grow sparsely and scattered through the water, or they may be so dense, that it is difficult to push a boat through, and at a little distance

to an unexperienced observer the tract might be taken for land. Yet their dark blue-green color is readily recognizable and wherever they are is surely lake, as Mr. Smith remarked. With this may be associated the pond-lily (Nymphaea) and Equisetums. In not too deep water they are adjoined by the cat-tails and the sedges (Cyperaceae like *Carex filiformis*) though one might still be knee deep in water* and legally (according to the Standard Dictionary) sedge flats on the seashore are classed as below high water mark. But when to the sedges are added blue joint (*Calamagrostis Canadensis*) and various shrubs and bushes, milkweed and goldenrod, etc., we are on firmer ground.

* Reed grass and several other grasses will also grow readily below water level.

THE ST. CLAIR DELTA.

BY LEON J. COLE.

INTRODUCTORY.

The delta at the mouth of the St. Clair river is something of an anomaly in that it is being formed by a river which serves as the outlet of a great lake, Lake Huron, but a short distance above. Since large bodies of water act as settling basins it would be expected that the river acting as the outlet of so large a lake would be comparatively free of sediment and consequently would be incapable of forming a delta of much size at its mouth. Attention has been called to this fact by Professor I. C. Russell* who explains that the shore currents in Lake Huron bring débris to the place of the outlet, the materials are swept into the river, and so carried, to be deposited in Lake St. Clair some forty miles below. It was at the suggestion of Professor Russell, and with the coöperation of Mr. Lane, the State Geologist, that I was enabled in the Spring of 1902, to make a study of the delta, which, however, was greatly limited in time, and the present report can only be considered as preliminary and rather fragmentary on that account. My thanks are due to both Professor Russell and Mr. Lane for suggestions and help at all times, and I am especially indebted to Professor D. C. Schaffner of Emporia, Kansas, who was at that time a student at the University of Michigan, and who accompanied me on my several trips to the St. Clair Flats, as the region of the delta is generally known, assisting materially in the rather arduous task of making borings with a hand auger. The government engineers stationed at Detroit, officers of the Grand Trunk Railway, and others have been uniformly courteous in placing at my disposal charts and maps and any information in their possession.

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* *Lakes of North America*, p. 40. Ginn & Co., Boston, 1895.
Rivers of North America, p. 133. J. P. Putnam's Sons, New York, 1900.

GENERAL CHARACTERS.

Enough has been said above to define the position of the delta under discussion, but some description of the general features of the region may not be out of place.

The River.—The St. Clair River, as stated above, is about forty miles long, and has a mean breadth of nearly one half mile. It is nearly straight, the greatest bend being against the Canadian shore at Sarnia; the course is slightly to the westward of south. Just below Lake Huron there is a stretch known as the Rapids, where the stream is narrowed by a spit reaching out from the eastern shore, and it is here that the current is strongest, some four and a half miles per hour. The banks, which are composed for the most part of blue clay with yellow clay and sand or gravel above, are low for the most part, having a height of fifteen to twenty feet for only a comparatively short distance, and on the upper portions of the river. Back from the river the land rises to low hills. At Algonac the stream divides into two large branches, the more direct being known as the South Channel, while the North Channel, which is the larger, being deeper and having a stronger current, turns rather sharply to the westward. This in turn divides some five miles below to form the Middle Channel, and again further along gives rise to the Chenal About Rond, or as is usually known locally, the Sny. These channels all give rise to minor distributaries in true delta fashion, as may be seen at a glance on the accompanying map (pl. I). The character of these channels is not clearly shown, however, on this plate, which makes the true channels appear much broader than they really are; there is usually a broad shallow on one side or the other, which suddenly dips off steeply into the comparatively narrow and deep channel. The steepness of the sides of these channels under water is most remarkable, being sometimes almost vertical for a distance, while a greater dip than 45° is probably characteristic. There are nine channels, including Baltimore Channel and the Ship Canal, which have a depth of over three fathoms to the bars at their mouths. Throughout the most of their length the main channels have an average depth of about thirty to forty feet, but the north channel, in the large bend south of Algonac, reaches a depth of ninety feet* and is sixty feet and more deep to some distance below the North

*Rough soundings were made here and at several other places, but so far as could be ascertained, there had been no appreciable change in the depth since the original charting 30 years ago.

In 1817 when the survey of the Flats was made by Lieut. H. W. Bayfield, R. N., the North Channel was known as the New Ship Channel, while the South Channel was called the Old Ship Channel, but since the building of the government piers at the entrance to the South Channel, the northern route has been used only by boats of very light draught bound for New Baltimore. The international boundary line follows the South Channel.

Channel Club House at the junction of the Chenal About Rond. The river above the head of the South Channel ranges in depth from thirty to sixty feet.

The Islands.—What is collectively known as the Flats consists of the various islands, large and small, which form the limiting shores of the channels. In the upper part of the delta these are often of a considerable size, but lower down they are cut up by the numerous small channels and by many artificial cuts which have been made in order to form boat-ways, and more commonly to get earth on which to build, the soil dredged from the cut being spread out on the surrounding low land, thus raising it to two feet or so above the water level. Russell Island and the upper parts of Herson, Squirrel and Walpole Islands are well above mean water level—some three to five feet—and are partially covered with heavy forests, while much of the land is under cultivation, making excellent farming land. The lower islands are wet and marshy, as a general thing not over a foot above water, and often with low, marshy, indefinable margins. They are almost perfectly flat, and in the summer are covered with a luxuriant growth of grasses and sedges, shading off into the cat-tails and rushes at the water's edge, which last extend far out into the shallow bays.

The Lake.—Lake St. Clair is about thirty miles long, from north to south, and twenty-four miles wide in maximum width. The greatest depth is twenty-two feet, and the mean depth over the central area is about twenty feet. The bottom is for the most part a fine blue clay or mud, covered in places with a thin layer of fine sand. The water surface is five and four tenths feet below that of Lake Huron. About one-fourth of the original basin of the lake has already been filled by the sediments brought down by the river, and the process is steadily going on.

Large shallow bays extend between the islands of the various channels; these seldom exceed four or five feet in depth, and in the summer become largely filled up with growing rushes. Even when the vegetation is at its highest, a person with his head a few feet above the grass can see for miles across what looks much like a waving green prairie, interrupted here and there by winding channels and ponds of water.

THE GROWTH OF THE DELTA.

Source of the Material.—The first question requiring attention in a consideration of the growth of the delta is the source of the material of which it is composed. As will be seen later, in the discussion of the borings, the greater part of the deposit is composed of clays of varying consistency and of sand, which is, in the main, fine, but ranges from that up to very coarse and gravelly. It has been suggested that we have here not a true delta, at least of the present St. Clair River, but in reality an old deposit through which the present river has cut channels for itself since it broke through at the southern end of Lake Huron and formed an outlet for the water of the upper lakes. Such an hypothesis would furnish an explanation of the height of the upper islands above the present water level, but the borings, together with other data to be presented, can leave no doubt that the foundation is a recent one and that the processes of its building up are still in action.

That the greater part of the sediments come from Lake Huron can hardly be questioned, though important additions are undoubtedly made by streams tributary to the St. Clair River, which are always turbid in times of freshet. Although, as noted above, Russell referred to the sweeping of débris into the river as due to certain currents in the lake, he made no analysis of this action: But Spencer* in describing his researches on the Algonquin Beach says: "The waves of the lake are encroaching upon the eastern coast of Huron, and consequently modern beach-making is not a characteristic feature, except in proximity to the mouth of some streams or in sheltered places, where terraces or bars are constructed. The encroachments of the lake upon the land have washed away, in many places, the bluffs upon which the Algonquin Beach rests," and Taylor† has applied this fact to the formation of the St. Clair Delta. He points out that the predominant run of the waves towards the south would tend to carry the débris formed by the cutting of the banks in that direction, and anyone who has ever watched material being moved along the shore by the waves striking at an angle will be prepared to agree with him. While the waves rush up the beach obliquely, the water runs back in a direction normal to the trend of the beach, and thus each time an object is moved, the resultant of the movement is in the direction of the wave action. This will be true regardless of the direction of off-shore currents. Although the resultant annual wind direction at Port Huron as ascer-

* Spencer, J. W.—"Deformation of the Algonquin Beach and Birth of Lake Huron;" Am. Journ. Sci., Vol. XII, p. 13, 1891.
† Taylor, Frank Bursley.—"The Second Lake Algonquin;" Am. Geol., Vol. XV, p. 171. 1895. Taylor was mistaken in regarding the delta as being built of pure sand.

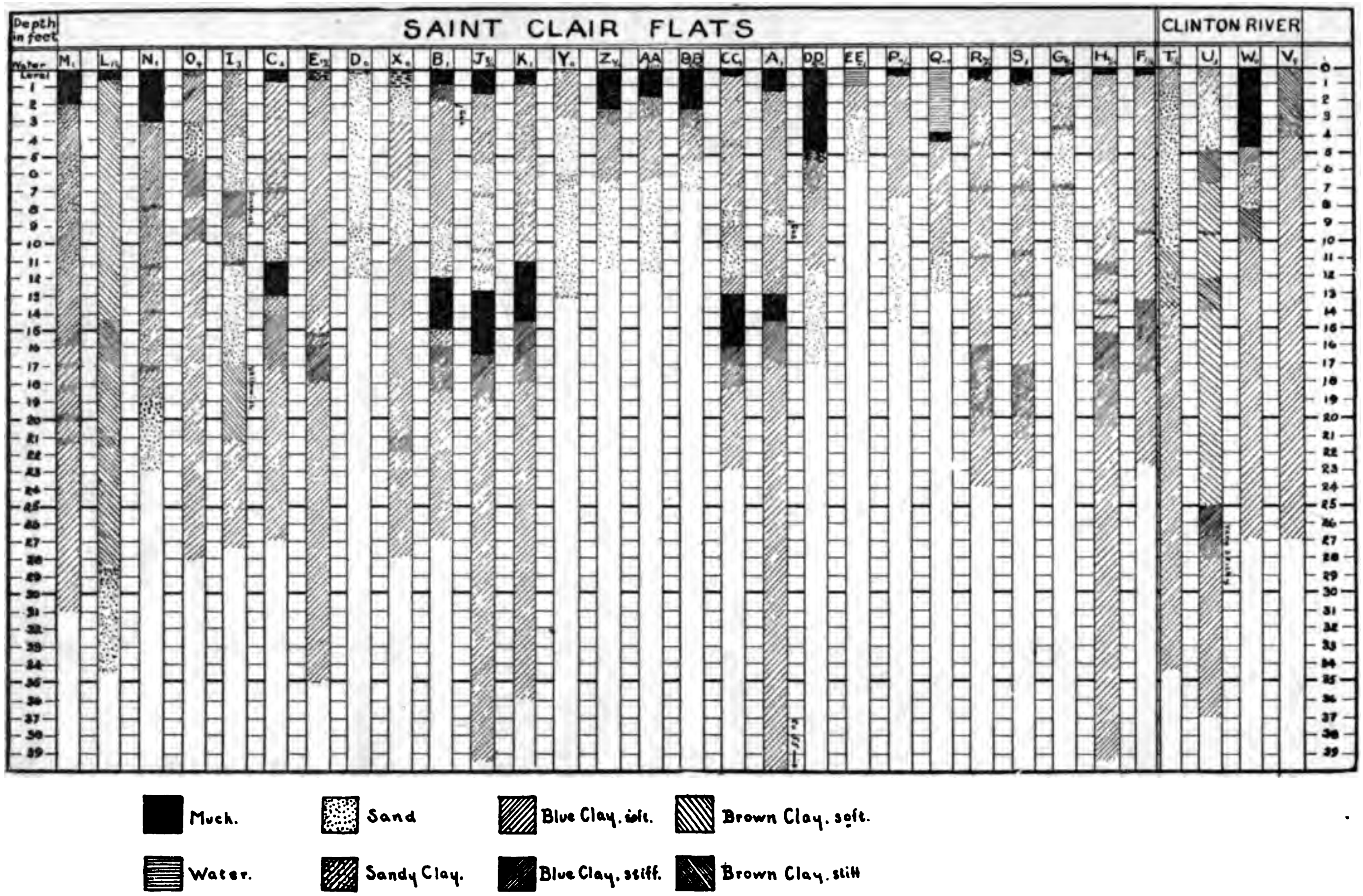


DIAGRAM OF BORINGS.

tained for a period of fourteen years is S. 51° W.* it is northerly for about four months in the year, and a moment's thought will show that it is only these latter storms that can have a great influence in moving the sand, as they alone will have the opportunity to produce large waves at the southern end of the lake. It should also be borne in mind that while the wind may blow from a southerly direction a greater part of the time, most of the severe storms, which would produce the highest waves, are northerly. Conditions similar to these have piled the sand in great dunes at the southern end of Lake Michigan, but in the case of Lake Huron the outlet is at this point, and the sand instead of collecting, is swept out and down the river by the strong outflowing current.

That the source of sediments is not confined to the east shore of Lake Huron is shown by the work of C. H. Gordon† who studied the destructive action of the waves at a point on the west shore some fifteen miles north of Port Huron. By comparison of surveys made in 1823 and in 1901, Gordon finds that one estate, which contained 184.90 acres at the earlier date, with a water front of something less than a mile, lost in the intervening seventy-nine years, 27.25 acres of land, which was washed away and carried into the lake by wave action—an average of .345 acres per annum. The total average recession of the shore line within this area was 449.46 feet, or an average recession of 5.7 feet per annum. The amount of material removed was 878,944 cubic yards, and it is safe to assume that a great deal of this eventually found its way into the St. Clair River, both on account of the direct wave action along the beach, as on the eastern side, and by the shore currents, which on this side run close to the shore and would catch the lighter materials that did not sink at once to the bottom.

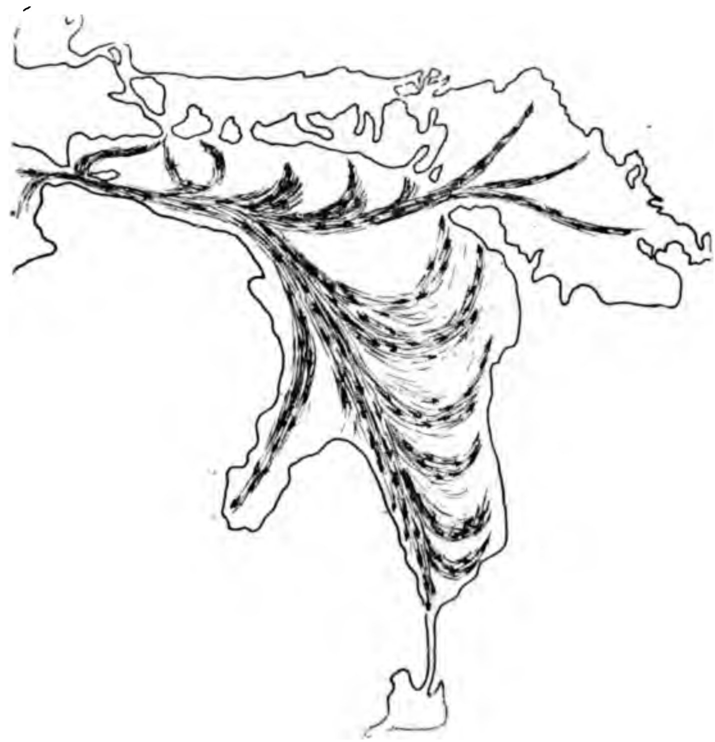
It is of importance to note the character of the sediments contributed at this place, where the bluff twenty feet or so in height gives a good section of the glacial deposits which compose the land. According to Gordon the section is made up as follows:

	Feet.	Inches.
1. Soil-top loam	1	6
2. Light colored, or drab sandy soil; small pebbles	9	9
2a. Brownish band: apparently a soil horizon		6+
3. Blue clay; more compact than No. 2a	7	
4. Blue clay; darker and more compact than No. 3	4	

See Harrington, Mark W.—"Surface Currents of the Great Lakes;" U. S. Weather Bureau, Bull. B., p. IV. 1895.
† Gordon, C. H.—"Wave Cutting on West Shore of Lake Huron, Sanilac County, Michigan;" Rept. Mich. Geol. Survey for 1901, pp. 283-291, figs. 5-7 pls. XI-XV. Lansing, 1902.

These materials being carried into the river, are re-assorted and deposited in Lake St. Clair, as we shall see later.

In the work mentioned above Harrington* charts the principal surface currents of the Great Lakes, as determined by bottle floats, and Fig. 1, which is redrawn after one of his maps, shows the results of these observations as determined for Lake Huron. It will be observed that the main current hugs the west shore; at the southern end of the lake a part



Fg. 1.—Chart showing principal surface currents in Lake Huron. After U. S. Weather Bureau.

of the waters turn to the eastward and up the eastern shore, but a large and definite current flows directly through the outlet into the river. The heavier sands being worked southward on both shores of the lake tend to choke the outlet, and it may be this current that keeps the channel open on the western side, while on the eastern side of the outlet a long spit has been built out, contracting the river to one-half its average width below and causing the rapids which occur at this place. Taylor† remarks that "The spit on the east side is well developed and its point has

*U. S. Weather Bureau, Bull. B. 1895.
† Am. Geol., Vol. XV., p 172. 1895.

been turned down stream by the current of the river," and adds, "The predominance of drift from the east shore has crowded the river over against its west bluff and filled in the old channel for a mile and a half on the east side,"—but it seems not unlikely that the west shore current has had more to do with keeping the river channel open on that side and preventing the formation of a spit than a great predominance of sand coming down from the other shore.

The water of the St. Clair River is usually remarkably clear for a stream that is forming a great deposit at its mouth, but after severe rainfalls and wind storms this is not true, for at such times the water becomes very turbid, though it can never compare with the Mississippi and its tributaries in this respect. The greatest source of this sediment is undoubtedly from Lake Huron, but that a large part of it comes from the small rivers flowing into the St. Clair, such as Black River at Port Huron, and Pine River at St. Clair, and from the erosion of the banks of the St. Clair River itself, had been clearly shown by Wheeler*, who made a careful examination of the matter for the United States Engineer Office, to determine the influence of the cutting away of the right bank of the stream in obstructing navigation. It was found that the right bank here, which is composed of much the same kinds of soil as that described above, in Sanilac County, but not so high on the average, is similarly being cut back by the action of the current and waves, the swells produced by passing steamers being especially effective. At one place between St. Clair and Marine City there is about two miles of nearly continuous erosion on a bank eight to fifteen feet high, going on at a rate of two to three feet a year. The highway had been set back twice and there was in 1885, but seven feet between the fence and a vertical bank at one point of the road, and for a quarter of a mile there was barely room for two teams to pass. The greatest erosion was on a three to five foot bank near Marine City, where the wash had been ten rods in forty years.

Erosion is also taking place on the Canadian side of the river, as noted by Wheeler, thus tending to make the river broader and shallower, but no detailed observations were made on that side, and his estimate of the amount of material removed in a year applies only to the American side of the stream. By a rather elaborate method he estimated that the under water erosion on the inclined sides of the channel bed amounts annually to 52,800 cubic yards which is nearly double that above water on the banks of the river; the sum total would thus be in the neighborhood of 79,000 cubic yards removed in the course of a year. But measure-

* See report of O. B. Wheeler, Assistant Engineer, in "Preliminary Examination of Saint Clair River and Saint Clair Flats Canal, Michigan;" Ann. Rept. Chief of Engineers, U. S. Army for 1885, Part III, Appendix LL 21, pp. 2199-2202. Washington, 1885.

ments made after a severe storm showed that under such conditions a far greater amount of sediment than this may come down from Lake Huron and the tributary rivers in three or four days. In making this estimate samples of water were taken while the turbidity was about at its highest, the solid matters weighed, and the amount carried by the river computed on the basis of a discharge of 233,726 cubic feet of water per second, as ascertained by the Lake Survey. In a quart of water from the bottom of the river at a depth of forty feet the solid matter was found to weigh one and two-thirds grains. Computation on this basis gave 72,000 tons as the amount of sediment being carried down the river in a day, or 216,000 tons during the three days' duration of the storm. Allowing eighteen and a half cubic feet of clay to the ton, this would amount to 148,000 cubic yards, or nearly twice as much in this short time as is eroded from the right bank of the river in a year.

The amount of sediment found by Wheeler is about two and one-half times as much as was found in samples that I took on July 4, 1902, at a point in the Chenal About Rond a little over two miles below the North Channel.* A heavy downpour of rain occurred on the night of July 2d, accompanied by a high southwesterly wind, and by 2 p. m. on the third, the water at this place had become very roily. On the fourth, the channel was still roily and the roiliness had extended into the bays, but only in the deeper parts where there is probably some current; by noon on the fifth, the channels were clearing up, but the roiliness had spread completely over the bays even into the shallow water among the grass and rushes near shore and into sheltered coves.

The suspended matter gives the waters of the channels and bays, which is usually bluish or greenish, a peculiar yellowish or even at times a whitish or milky color. Examined in a glass vessel it is seen to have a flocculent appearance, and upon settling produces a fine clay of varying consistency.

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* The samples of water were taken as the roiliness was about at its highest and yielded the following measurements:

(1.) Sample from near the bottom (24 feet) in mid-channel—
Volume of water in sample.. 720 c.c.
Weight of solid material contained.............................. 0.027 grams.
This is equal to 0.0375 grams of sediment to the litre, or 0.548 grains to a quart of water.

(2.) Sample from surface in mid-channel—
Volume of water in sample.. 723 c.c.
Weight of solid material... 0.029 grams.
Equals 0.04 grams to the litre.

(3.) Sample from surface near the shore—
Volume of water.. 715 c.c.
Weight of solid material... 0.024 grams.
Equals 0.0335 grams to the litre.

It will be seen that in mid-stream a slightly greater amount of sediment was found at the surface.

The sample from the bottom was obtained by lowering a weighted and stoppered bottle, and then pulling out the stopper by means of a separate string attached to it.

The determination of the amount of sediment in these samples was made for me by Mr. Howard S. Reed, of the Universtity of Michigan.

Deposition of Sediment and Formation of Islands.

As is to be expected the sand and heavier materials brought down by the river are the first to be deposited upon a slackening of the current as the various channels open out into the large bays and the lake, and they accordingly contribute to the formation of bars around the mouths of all the outlets. That the water of the channels is appreciably higher than in the bays is shown by the strong currents obtaining in the small cuts connecting the two. Such cuts have been dredged out in many places often where the distance through an island from the channel on one side to the bay on the other is but a few rods, and not only does the current which at once sets in keep these canals open, but in many cases scours them out to fully double their original depth, while at the same time bars of corresponding size are formed around their outlets, where the water is no longer confined to the narrow channels but spreads out into the broad bays and is diminished in velocity.

A cut which was dredged for Mr. F. H. Bryant, connecting the Chenal About Rond with Pollet Bay, which in turn opens into Anchor Bay, may be taken as an example. When dredged in August, 1900, this cut was 32 feet wide, six feet deep and 900 feet long. Mr. Bryant writes me that in May, 1903, it is 10½ feet deep and 37 feet wide, so that 6,550 cubic yards of earth have been cut away by the water in less than three years, or slightly more material than was originally dredged out. The deep water of the channel now also extends some distance into Pollet Bay, but is terminated by a shallow bar of its own formation.

The sands which form these bars are probably for the most part rolled along the bottom; the lighter materials suspended in the water are deposited more evenly over the entire areas of the bays, and even far out into the lake.*

In the following discussion of the deposition of the sediments only subaqueous deposition will be considered at first, and the building up of the islands above water level will be taken up later. In this study the results of the borings made at various places will be of great assistance. These borings were made by hand† with a two-inch auger; as the auger

* Wheeler, in his report mentioned above (U. S. Engineer's Report 1885, Part III, p. 2201) mentions observing the rolliness extending six miles into the lake below the end of the ship canal.

† Altogether thirty-one borings were made, aggregating a depth of 693 feet, or an average of 22⅓ feet to each boring, records and samples of the materials passed through being taken when the drill was pulled up at short intervals. On Plate II, the results of these borings are shown diagramatically, their depths being reduced to water level at the place of boring, and at the time the boring was made. It will be seen that a source of error in the comparison of different borings has been introduced in this way, for two reasons; (1) the water level is higher towards the head of the delta than around its periphery, and (2) there was undoubtedly some fluctuation in the general level of the water surface during the time that these records were being obtained. The second of these factors makes it impossible to correct for the first; but it is believed that if they are kept in mind the general conclusions need not be affected by them. The borings were lettered consecutively as made; their locations will be found designated by these letters on the map (Plate I).

was lowered sections of gas-pipe* were coupled on, and were screwed off again as the auger was raised.

Two generalizations of special importance to us now may be made from an examination of Plate II. In the first place it will be noted that in more than one-third of the borings (C, E, B, J, K, CC, A, R, S, H, F), a layer of stiff blue clay, two to three feet thick, was struck at a depth of 14 to 16 feet, and that below this in all cases it gradually became softer and continued so, passing into a homogeneous soft blue clay through which the drill could usually be *pushed* without turning, as deep as the hole was put down, in one case to 55 feet. In fact, in the later borings the drill was not put down as far as it could have been, but when this stiff clay was struck with softer below, the boring was only continued deep enough to make sure we were in this homogeneous layer. The deepest boring made was to 56 feet below the surface of the ground; it was not discontinued at this point so much on account of the difficulty of getting the drill down as pulling it back out, because of the softness of the clay, through which a clean hole of the diameter of the auger could not be maintained. From data obtained from wells, put down on the mainland in the vicinity of the Flats†, and from the preliminary borings and final excavation for the St. Clair tunnel of the Grand Trunk Railway, it seems certain that this is the same great bed of clay that covers the Antrim "bed rock," (earlier called St. Clair shale) of all this region, varying from a thickness of 80 to 100 feet at Port Huron to 150 to 200 feet at Algonac. In the subsequent descriptions I shall speak of this as the *bottom clay.*

The second point to be observed is that in the case of six of the borings (C, B, J, K, CC, A), a stratum of muck 1½ feet to 3 feet in thickness was found at a depth of 11 to 13 feet. This stratum of decaying vegetable matter was of a rich dark brown color, and pieces of plants, such as stems and grass leaves, could still be picked out, and seemed to be in a fair state of preservation. The decay going on in this stratum produces gas, which often collects in some quantities where there are layers of tough clay above; thus in borings A and B, as the drill was withdrawn after passing through a layer of rather stiff clay, at about 9 feet in the former and 2 feet in the latter, there was a violent bubbling of gas. There was not enough of the gas to produce a continuous flame at the open top of the

* Two lengths were used—4 feet and 8 feet; the depth of boring could thus be calculated directly at any time by knowing merely the number of sections of pipe that had been put down.

† See Geological Survey of Michigan, Vol. V, Part II. "The Geology of Lower Michigan, with reference to deep borings;" edited from notes of C. E. Wright, by Alfred C. Lane, Lansing. 1895; also, Annual Report for 1901.

hole, but it would produce a considerable flash when lighted. There is a place in Muscamoot Bay, known as the Gas Well, and so designated on the Lake Survey charts. I was told that at this place the gas bubbled up continually through the water from holes in the bottom, but when I visited the place there was, unfortunately, so high a wind that I could not locate the spot on account of the roughness of the water. It is also said that ice does not form over this particular spot in the winter. I was later directed to another locality on the shore of Fisher Bay opposite a pond known as Little Lake (See *, Plate III), where the waters of the bay wash up against a vertical bank about a foot high above the water. At several places continuous streams of small bubbles were seen rising to the surface from little holes in the clay bottom, close to the bank, where the water was about a foot deep. A stick pushed down for two or three feet anywhere in the immediate neighborhood, and then withdrawn, would make a hole for the escape of the bubbles, showing that the gases which formed underneath were prevented from escaping, to a large extent, on account of the deposits of clay above. In borings, C, CC, J, and K no gas was noticed; the clay above the muck in these places was more porous on account of the greater amount of sand it contained, and no gas has accumulated below. The probable significance of the great deposit of bottom clay and of the stratum of muck, which, there seems little doubt, forms a single horizon, will be considered later in the historical discussion of the region.

Some of the deep borings, although they go deeper than 17 feet, which is the lowest record for the top of the bottom clay, do not show any evidences of that bed at all. Borings L and N illustrate this well, probably also I, for although a layer of harder clay was struck at this place at a depth of 17 feet, it was yellowish in color, thus differing from the stiff blue clay found at the top of the bottom bed in all the typical cases. Unfortunately, in many cases where much sand was found, near the surface, without any clay, it was impossible to put the borings down more than 12 to 15 feet on account of the caving in of the sand along the sides of the hole (D, Y, Z, AA, etc.). The deep borings mentioned above undoubtedly represent old channels which formerly cut through the bottom clay at these places, but were abandoned and have become filled in. In some places a smaller stream still follows the path of the earlier channels; in others the channel has become entirely closed at its head and is completely filled in, or may still have dead water occupying a part of the old course. The first of these conditions is illustrated by Blind Channel, which branches off from the Canadian side of South Channel a short dis-

tance below Russell Island (see Plate I). That a channel about as wide as the present South Channel used to flow through here is shown (1) by the old banks (indicated on the map by dotted lines at the head of the channel) which are some three to four feet high and are a conspicuous feature; (2) by the vegetation, which changes markedly in character from the low ground which fills the old channel, to the higher ground which formed its banks,—from swampy ground overgrown with sedges, one passes to dry ground with a vegetation of grass and other plants that require such a soil, e. g., yellow-eyed grass (*Xyris Caroliniana*), the common blue violet (*Viola palmata cucullata*), and bastard toad-flax (*Comandra umbellata*); (3) The borings indicate the same thing; boring N, which is taken on the bank of the present stream and is about in the middle of the old channel, strikes the gravel bottom of the old stream at a depth of 19 feet. Boring O is on the crest of the old bank, and here gravel was struck at a depth of 3 feet. The present stream at this place is 7 to 10 feet deep; it is shallower at its head, showing that a bar is forming there which will probably cut the rest of the channel off from the waters above and connect it into the type to be considered next.

This stage in the process is well illustrated by Drouard Channel (see Plate III), which, however, was never a channel of major importance.

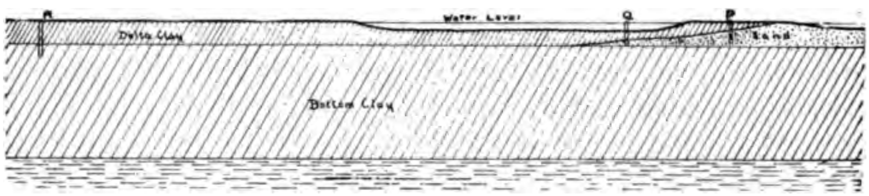
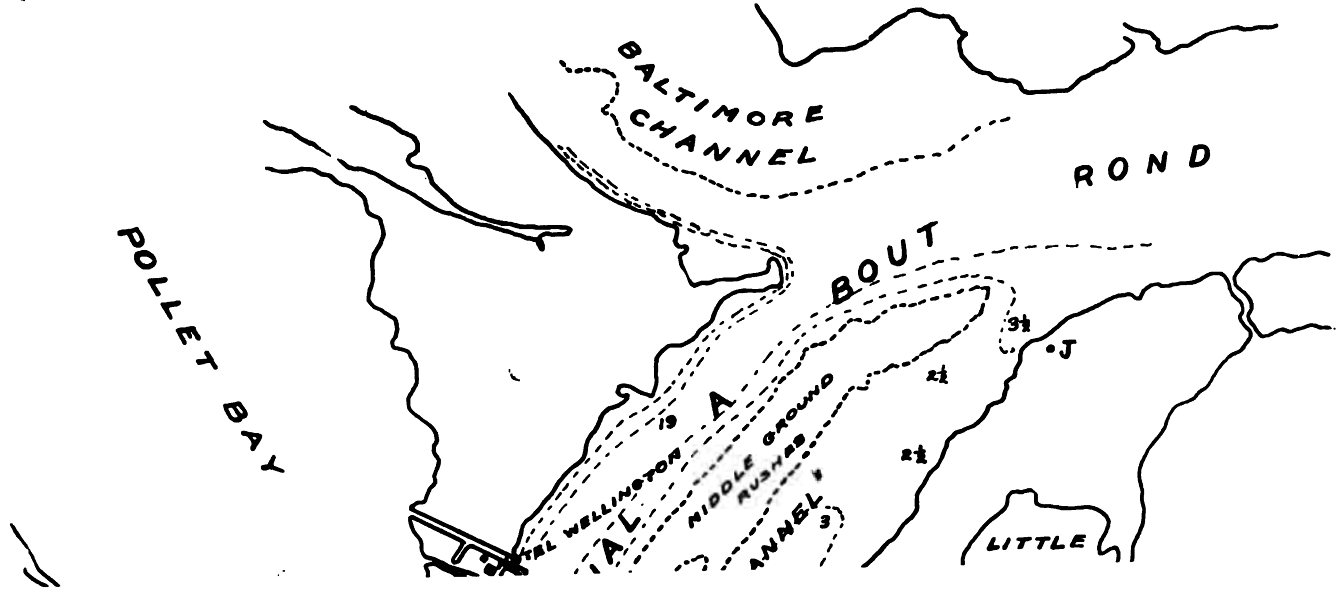


Fig. 2.—Diagram showing probable section through borings P, Q, R. Vertical scale two times horizontal scale.

The head of this channel has been entirely closed by a sand bar which formed across it, and which is shown in borings P and Q. The blind channel thus left opening into Goose Bay is now slowly filling with the fine sediments which find their way into its waters, and by the action of vegetation. The first of these processes is very slow, for it is only after severe storms, when the waters become very roily, that any considerable amount of the sediment will extend up into a channel of this nature. That the action of vegetation in filling quiet waters of this kind is more important than is usually supposed has been shown by students of plant ecology, and it is probable that under such conditions as we have here, the process is not essentially different from what it is in the small glacial lakes in the interior of the state*, except that fewer plant zones are concerned.

* Reed, Howard S. "A survey of the Huron River Valley,—I. The Ecology of a Glacial Lake;" Botanical Gazette, Vol. 34, pp. 125-139. 1902.


BALTIMORE CHANNEL
ROND
BOUT
POLLET BAY
A
19
MIDDLE GROUND
RUSHES
ANNEL
3
3½
2½
2½
J
LITTLE

It is probable that Drouard Channel was shallow even when functional and that its bed was on the top of the bottom clay. On this supposition, a small piece of what was evidently decaying wood which was struck at this level could be interpreted as a piece of water-logged wood that had sunk to the bottom of the old channel. Fig. 2. represents a probable cross section through borings P, Q, and R.

The complete closing of the Drouard Channel is a comparatively recent event, and may well have happened since the advent of white men to the region; a similar condition, but somewhat further advanced, is shown by the blind water marked "Old Channel" on the same map; and it is only a question of time before the connection from the point at boring J across to the Middle Ground will similarly cut off the present water known locally as "Blind Channel," the Middle Ground will be built permanently above mean water level, and the Chenal About Rond will be narrowed to a third of its present width at this place. When the water of Blind Channel becomes dead the growth of the bar which already extends down from the Middle Ground past the mouth of the Doty will be facilitated and that channel will eventually be added to the number of dead streams that are filling up to become land.

While the formation of bars across their heads is the common method of the closing up of channels, it is also one which acts comparatively slowly. Much more rapid changes are produced by another cause, which is not only an important physiographic agent but is also a serious menace to early spring navigation. This is the formation of ice dams in the river and distributaries and is again largely due to the peculiar relation which the river bears to Lake Huron. When the ice breaks up on the lake in the spring it is often driven by the wind so that it forms a great pack at the end of the lake. Such a pack, which formed in the spring of 1901, was held by jamming in and forming a bridge across the head of the river, until on April 27, a field of ice 12 miles in width had accumulated. The ice which went down the river again gorged near Algonac, forming a complete dam, and lowering the water on the Flats until many acres of the shallower portions were above water, while in the river above the level was correspondingly raised. At Marine City on May 1, the water was 4 feet above the normal level. The effect of such obstructions as this in the changing of old channels, and in causing breaks to occur across the existing embankments above the dams, when they form in the lower parts of the delta, may readily be understood.

Little Lake shown on Plate III, may be taken as a good illustration of another process which is contributing materially to the increase in

area of the island masses. This shallow pond undoubtedly represents what was originally a small bay or cove off from Fisher Bay; by the action of wind and waves a bar was raised which has eventually shut it completely off from the large bay, except for a very narrow connecting channel. This process may be seen in various stages at many places on the Flats; in fact, on this same island just north of the Doty Channel is a small pond now entirely cut off from the bay, which evidently represents a still later stage than that of Little Lake. When a pond has become entirely enclosed in this way, its ultimate filling in depends entirely upon the encroaching vegetation and the debris formed by its decay, except in case of exceptionally high water when the whole island is flooded and sediment-laden water from without finds its way in.

At the Flats, lagoons and ponds may also be formed in another way, which is common to delta-formation, and is especially noticeable in the case of the delta of the Mississippi. As has been noticed, each of the distributaries as it advances builds a pair of embankments or levees, and tends to form a secondary delta at its mouth; the levees of the neighboring secondary deltas may unite and so enclose the bay which lies between. Fisher Bay and the upper end of Muscamoot Bay are already nearly closed in by land in this way, and will eventually become lagoons unless they become filled before the land across their lower sides has completely joined.

We have so far considered mainly the growth of the islands to a level with the water surface; the question remains, How do they become raised above the level of the lake? Taking into account for the present only the lower portions of the delta, there are two factors which seem chiefly to be concerned in its growth: (1) high water, and (2) vegetation. High water in Lake St. Clair may be caused by freshets and heavy rains, or by southerly winds. Either of these may raise the general level a foot or more, and sediment is thus deposited among the grass roots, and on land which is out of water at normal levels. It is obvious that these influences will not account for the height of three to five feet above water of the upper islands, but this is a feature of most deltas, and is here to be accounted for, in large part at least, in the same way. A stream carrying considerable sediment and forming deposits at its mouth, must change its grade as this goes on, and as a result the head of the delta travels upward along the stream.* Later, if the load of the river becomes reduced at any time, corrasion will begin along its upper reaches, and

* The real head of the delta is probably nearly five miles above Algonac; a small bay which starts off on the Canadian side here is continued by low ground, which leads down to a junction with the Chenal Ecarte (see Plate I) and undoubtedly represents a former distributary. The Chenal Ecarte itself leaves the main river about two miles above the head of Russell Island.

the stream will thus cut into the deposits at the head of the delta. Another factor which has undoubtedly increased this effect in the case of the St. Clair River is the differential uplifting of the Great Lake region in the northeast which has been going on in post-pleistocene time and is still acting. It was this tilting which brought the St. Clair River into existence again after the outlet of the upper lakes had been to the northeast, and its subsequent action has been to increase the gradient of the stream throughout its whole length, thus causing it to cut more deeply into the deposits that had been made.

HISTORICAL.

In explaining some of the special features of the St. Clair delta it will be necessary to take into consideration the geological history of the region—at least that portion of the history following the retreat of the last great continental ice sheet.*

The first thing to be accounted for is the great bottom deposit of soft blue clay which underlies not only the Flats and Lake St. Clair but extends over all the low basin between Lake Huron and Lake Erie. Such a deposit must have been laid down in a large body of water which covered the region for a long period. This was the case during the existence of glacial lakes Whittlesey and Warren, when the ice-front stood at a point about a mile and a half north of the site of the present village of Saint Clair, and after it had retreated farther northward to positions now covered by Lake Huron. It is noteworthy that no pebbles or larger stones were struck in the bottom clay, which further indicates that it is an off-shore deposit. The conditions in the St. Clair basin when the ice had retreated further, lowering the level in the Ontario region below that of Lake Erie, and thus bringing Niagara Falls into existence and making Lake Erie into an independent lake, are not altogether clear. If the Trent River served as the sole outlet for the waters of Lake Algonquin for a time, it is possible that the St. Clair basin was drained while that condition prevailed; and it is certain that during a large part of the existence of Lake Algonquin its waters found their way into Lake Erie through a broad strait which occupied the valley of the St. Clair and Detroit Rivers

* The literature on this subject during the last twelve to fifteen years is considerable, and is scattered through the various geological publications. Among the principal contributors may be mentioned Gilbert, Spencer, Taylor, Leverett, Upham and Bell. While they do not agree on all points, there seems to be a general agreement as to the major steps in the process, and I have attempted to follow those views most generally accepted. A very readable brief account of these changes has been written by Taylor, called "A Short History of the Great Lakes." It was published as one of the series of "Studies in Indiana Geography," edited by Charles Redway Dryer; Inland Publishing Company, Terre Haute, Indiana. 1897.

and Lake St. Clair. The beaches formed at this time are well marked along the St. Clair River and around the lake. It seems probable that this connection was a strait rather than a river with any considerable current, as the sediments deposited in this case would be fine and would blend with the deposits already made while the region was covered by a great body of water; in the borings at the Flats, no deposits could be found which could be interpreted as the bottom deposits of a river existing at that time. Nor was any horizon found which indicated the nonexistence of a lake in the St. Clair depression at the time when the outlet of Lake Algonquin was supposed to be through the Trent River.

But the fact that the Nipissing beach dips toward the south end of Lake Huron makes it reasonable to suppose that at that time the St. Clair region was relatively elevated, and was higher than the level of the Nipissing lakes. It was still, however, probably low, marshy ground, lying in a saddle between the southern end of the Nipissing Lake Huron and the western end of Lake Erie, with its drainage system consisting of small streams flowing either northward through the St. Clair Valley, or southward to Lake Erie, or possibly in both directions at different, or even at the same times. The surface of the old lake deposits—the "bottom clay" —was thus exposed, and became covered with plant life. The evidence of this is found in the layer of decaying vegetation lying at a depth of about twelve feet under the present delta.* Furthermore, the clay immediately beneath the muck is tougher than that further below, and is also darker, results due respectively to surface exposure and to discoloration by decaying vegetation. Exactly similar conditions are to be seen at the present surface (see borings C, B, Z, BB, etc.) The Nipissing vegetation over this area probably consisted mostly of sedges and grasses, and it consequently must have taken a considerable time for the two to three foot stratum of muck to be formed.

That the northeastern elevation which shifted the outlet of the Nipissing lakes back to the St. Clair River is still going on seems pretty well established. This change in level undoubtedly accounts for the well-known drowning of the streams that flow into the western end of Lake Erie, but that. as Taylor† suggests, the shallow water covering the lower part of the St. Clair Flats may be taken as a similar drowning of the delta, does not seem to accord with the facts. In fact, just the contrary must be the case; for all of Lake St. Clair lies to the northeast of an isobase normal to the direction of tilting passed through its outlet, and consequently its bottom and all its shores must be undergoing ele-

* No fossil remains of animals were found in the borings, but a large number of shells of Unionidæ have been brought up by the dredging along the Clinton River.

† Taylor, F. B. "The Second Lake Algonquin;" Am. Geol., Vol. 15, p. 173. 1895.

vation relative to the outlet.* This would tend to raise the Flats above water rather than to drown them, and has already been mentioned as a probable factor in that process (pp. 2, 19). On the other hand it cannot be denied that all the tributary streams between the head of the Detroit River and Lake Huron are of the type known as drowned streams. As examples of such may be taken the Clinton River and Swan Creek, opening into Lake St. Clair, and Pine and Black Rivers tributary to the St. Clair River; the streams on the Canadian side I have not had opportunity to examine, but Chalmers† reports similar conditions. The drowning of these streams is to be explained, it seems to me, by the great volume of water now flowing out of Lake Huron. During the time of the Nipissing Great Lakes, when the land in the region under discussion was all above water, the streams cut for themselves deep channels; since the St. Clair outlet again came into use, the amount of water coming through it has been so great that not only has it cut the bed of the St. Clair River much lower than the bed level of the tributary streams, but its surface is also higher than was theirs. and so by backing their waters has converted them into drowned streams. This drowning, instead of progressing, however, is being lessened in these streams by the differential tilting which is taking place.

RATE OF GROWTH.

Attempts to obtain a fairly reliable determination of the rate of growth of the delta as an index to the length of time it has been building have not given very satisfactory results. One way to obtain this is by a measure of the amount of sediment brought down by the St. Clair River in a given time; such observation would have to cover at least a year to be of any value at all for this purpose, and should preferably extend over several years. Except at times of storms the water is very clear, and the amount of light sediment (i. e., not taking into account sand rolled along the bottom) which may come down in a single storm has been computed; from the observations of the Weather Bureau it would be possible to find the average number of storms per year for a number of years, but even then results figured on this basis would be of little value on account of the great variation in the amount of sediments that would be produced by different storms, for we have no measure of what this would be under the various conditions of these storms.

* See Gilbert, G. K. "Recent Earth Movements in the Great Lake Region;" 18th Ann. Rept. U. S. Geol. Survey, Part II, pp. 595-647. 1898.
† Summary Report of Geological Survey of Canada for 1901, pp. 167-168.

A comparison of various maps of the Flats gave no more satisfactory results. No accurate survey was made until that of the U. S. Lake Survey in 1867-71, and that only outlined many of the islands in a general way. On Plate I the outlines of the chart made from this earlier survey are represented by red dotted lines; those from another edition, with additions made in 1902, are shown by the unbroken blank line. It will be noticed that in the latter Herson Island is extended to about twice the size it was on the earlier map. Blue prints from the recent survey made of the Flats by the State (in 1900 to 1901) were furnished by the land office, and have been reduced to the scale of the Lake Survey Charts; these shore lines, where they differ appreciably, have been put in with green dots and dashes. The earliest obtainable map of the Flats (Plate IV) made from the surveys of Lieut. Bayfield, R. N., in 1817, represents the Flats only in a general way, and is of no use in the present connection. According to this chart there was in 1817 about twice as much land above water as at present. An element to be taken into consideration is, that whereas on the charts the shore of an island is represented by a definite line, such is far from the condition obtaining on the islands themselves, and a rise or fall of a few inches in the water level may bring a great many acres out of water, or may submerge as much below its surface. Taking all these things into account, however, there still seems to be no doubt that the difference in the extent of Harsen Island as shown on the maps for 1867-71 and 1900 and 1902 really represents a growth of the island on its lower side; but in all probability this growth has not been so great as would appear on the map, which in any case indicates only areal expansion, and gives no measure of the amount of material that has been added. It is to be noticed particularly that no extension of the embankments along the principal channels is indicated, with one exception; in fact, in the case of the mouth of the Chenal About Rond, the land is extended farther on the Lake Survey Charts than by the State Survey; this is probably due to the plotting of rushes in shallow water as ground.

In the winter of 1887 a survey was made by H. D. Bartholomew on the ice, in which he "attempted to include within the surveyed portion of this territory all of the submerged lands upon which aquatic plants could be discerned either upon or through the ice."

A series of soundings, if made now, to compare with the careful soundings made in 1867-71, would be apt to give a much better index of the growth of the delta than can be obtained from the outlines of the islands.

THE CLINTON RIVER DELTA.

It will be noticed on Plate I that the Clinton River opens into Lake St. Clair at the end of a considerable projection of land, which forms the southern limit of Anchor Bay on the western shore. On the map this has much the appearance of a delta, which is remarkably large in comparison with the St. Clair delta, considering the size and conditions of the stream which alone can supply it with materials. Investigation showed, however, that most of the land is relatively high and is under cultivation. A distinct bank from about 5 to 6 feet high along the lower parts of the river, to 9 feet or more higher up, could be distinctly traced, and its position is marked by dotted lines on the chart. Between these banks is the meander plane of the river; outside is undisturbed glacial till. The river has formed a small delta deposit, it is true, beginning about a mile above the present mouth of the river. Black Creek* is the principal distributary from the main channel, and has carried much of the material a mile and a half to the southward, where it has built a small delta of its own.

In the few borings made along the Clinton River (T, U, V, W), although what was apparently bottom clay was struck in each, its tougher surface horizon, at about 15 feet, was not found—with the possible exception of boring T. It is evident that some of these borings (at least U) were on the site of a former channel which had cut rather deeply into the clay of its bed.

No deep stratum of muck was found in any of these borings.

ECONOMIC IMPORTANCE.

The St. Clair Flats have long been a popular summer resort on account of the facilities for boating, and the good fishing and hunting, and the American side of the South Channel is well built up with summer cottages and hotels, which are much more scattered on the other channels. The higher ground of the upper islands is partially forested, and there is also a considerable amount under cultivation. Walpole Island is set aside as an Indian Reservation by the Canadian government, and the land is cultivated by the occupants.

* Black Creek is shown relatively too broad on Plate I, in fact, I believe it has now been practically shut off at its head by dredging and the building of embankments along the main channel.

Aside from its use as a summer resort it would seem that what is still unsettled of the American Flats is of most importance to the people of Michigan as possible ground that can be turned to the use of market gardening. The land is at present very cheap, and by dredging at intervals and spreading the soil thus procured out upon the remaining area, a fairly good land can be obtained which will grow many kinds of market produce if properly cared for. If any amount of this were raised, what could not be used by the hotels and cottages on the Flats could readily be shipped to Detroit, either by boat or upon the electric railway which skirts the lake on the mainland.

When the present investigation was undertaken it was thought possible that beds of marl might be found somewhere in the region, which, together with the abundant and excellent clay, could be utilized in the manufacture of Portland cement. Marl beds were hardly to be expected in such places as the borings were made; but this does not make it impossible that they should be found, for instance, by borings made in Anchor Bay, though I think that even here it is rather unlikely.

SUMMARY AND CONCLUSIONS.

1. The St. Clair delta is peculiar in being built by a river which serves as the outlet of a large lake.
2. The materials which compose the deposit are fine sand and clay, and are derived for the most part by the action of the waves on the shores of Lake Huron, with the addition of materials brought in from rivers tributary to the St. Clair, and some eroded from the bank of that river itself.
3. The delta is in most respects a typical low-grade delta, the general laws of the deposition of sediments under water holding as in other cases.
4. The recent northeastern uplift has assisted the stream in cutting through the deposits at the head of the delta since forming them, thus bringing this portion higher in relation to the water level.
5. The clay upon which the delta is built is a deep-water deposit some 150 to 200 feet thick laid down at the time of the existence of glacial lakes Whittlesey and Warren. The surface of this "bottom clay" is but 14 to 16 feet below the present lake level.
6. At the time of the Nipissing Great Lakes this region was drained and covered with vegetation. The muck formed by the decay of that vegetation is now found as a stratum two to three feet thick immediately above the surface of the bottom clay.

7. The "drowning" of the streams tributary to the St. Clair River and Lake St. Clair is due to the large volume of water now flowing through, rather than directly to the uplifting in the northeast. The effect of this tilting is to diminish the drowning in this region, instead of increasing it.

8. Sufficient data are not at hand for determining the rate of growth of the delta with any accuracy.

By a process of reasoning backwards it may be assumed that 5,000 to 10,000 years has been required for the formation of the present delta. This presupposes that Taylor* is right in correlating the beginning of the upper, wider gorge of Niagara Falls with the shifting of the Nipissing outlet back to Port Huron, and that the estimate of time which has been consumed by the Falls in cutting back from this point is approximately correct. While this does not seem too long a time for the formation of the delta, still we have seen that the deposit which has been laid down by the river is not nearly so great as Taylor supposed.†

Instead of being 25 to 30 feet below the present water level, the bottom of the delta rests upon clays only 14 to 16 feet below the surface, though deposits have been made to a greater depth, to be sure, in the beds of old channels which cut through the bottom clay. Since the Nipissing beach, if projected, would pass 35 feet below the present level of Lake St. Clair, it follows that at the time that lake was in existence the land at this place had an elevation of 20 to 23 feet above its water surface.

Supposing the above determinations of time to be approximately correct, with a continuance of present processes Lake St. Clair would be completely filled by the delta of its feeding river in 20,000 to 40,000 years (assuming that the basin has already been one-fourth filled), except probably for one deep channel connecting the mouth of the present St. Clair River with the head of the Detroit River, which would then form a continuous river from Lake Huron to Lake Erie. Long before that time has elapsed, however, it is possible that on account of the dipping to the southwest; the Great Lakes will again be discharging through the Illinois River, with a consequent lowering of their level. This might again withdraw the water from the St. Clair outlet and convert the lake bottom into dry land.

9. Besides its value as a summer resort, portions of the Flats not now in cultivation may be made into productive land by dredging and grading.

10. The Clinton River has formed a small delta at its mouth with a land area of probably about 800 acres.

*"The Second Lake Algonquin;" Am. Geol., Vol. 15, pp. 167-171. 1895.
†*Loc. cit.*, p. 172.

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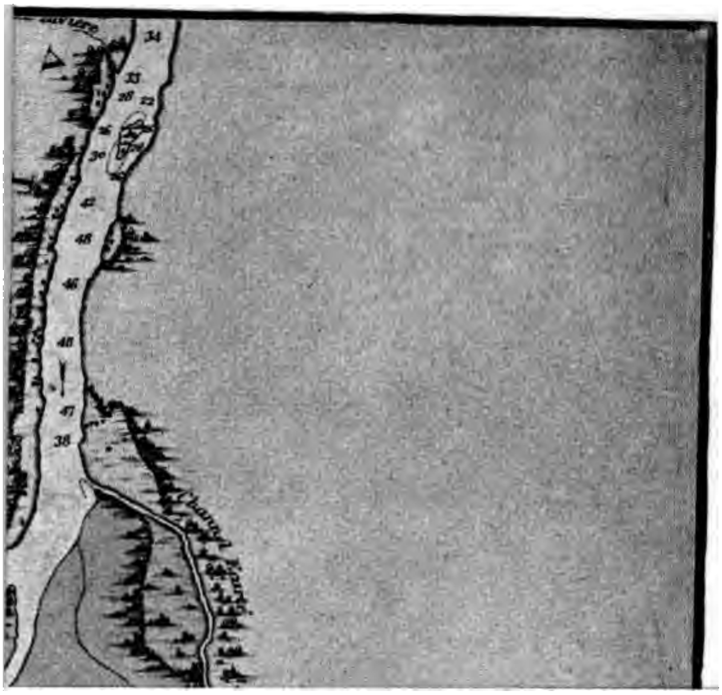
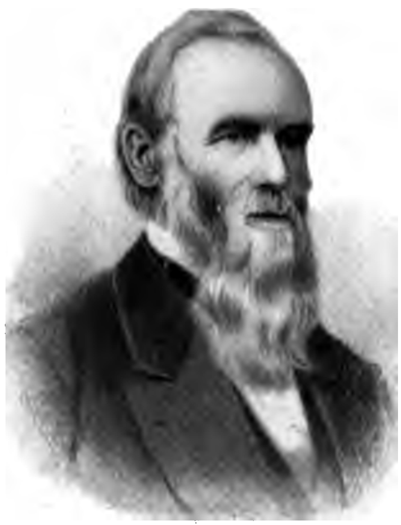


R. E. BUTTERWORTH.

AMOS RATHBONE.



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GEOLOGICAL SURVEY OF MICHIGAN J C Branner

ALFRED C. LANE, STATE GEOLOGIST

VOL. IX

PART II

THE GYPSUM

OF

MICHIGAN

AND THE PLASTER INDUSTRY

BY

G. P. GRIMSLEY

ACCOMPANIED BY TWENTY-NINE PLATES

PUBLISHED BY AUTHORITY OF THE LAWS OF

MICHIGAN

UNDER THE DIRECTION OF

THE BOARD OF GEOLOGICAL SURVEY

LANSING

ROBERT SMITH PRINTING CO., STATE PRINTERS AND BINDERS

1904

OFFICE OF THE STATE GEOLOGICAL SURVEY,
LANSING, MICH., July 26, 1903.

To the Honorable, the Board of Geological Survey of Michigan:

HON. A. T. BLISS, *Governor and President of the Board.*
HON. L. L. WRIGHT, *President of the Board of Education.*
HON. DELOS FALL, *Superintendent of Public Instruction and Secretary of the Board.*

GENTLEMEN:—Herewith I transmit as Part II, the concluding part of Vol. IX, a report containing the results of examinations and tests by G. P. Grimsley, of the gypsum resources of the State so far as they are at present developed. It also includes especial notes by W. M. Gregory on the alabaster area and some account of the general state of the industry, which Mr. Grimsley wishes to include at no extra expense to us.

With great respect, I am, your obedient servant,

ALFRED C. LANE,
State Geologist.

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ILLUSTRATIONS.

FIGURES.

ILLUSTRATIONS.

PLATES.

ERRATA.

Page 23, line 7, refer to Plate XXIX instead XIII.

Pages 47, 50, and index, Mr. Church's initials are M. V., not M. B.

Page 76, line 16, read Pinconning for Bay City. Also, the Detroit and Mackinac R. R. is thus spelled with a terminal c, while the division of the M. C. R. R. is spelled Mackinaw.

PREFATORY.

The writer of the following report was first interested in the study of gypsum and hard wall plasters, when he became a member of the University Geological Survey of Kansas in 1896. Three years were spent in a careful study of the Kansas deposits and of the methods of manufacture of wall plasters. This study was carried on in the field, library, and laboratory. The results of this work were published in Volume V of the Kansas Survey reports.

Since that time the gypsum deposits in Oklahoma, California, and Ohio have been investigated; and in the laboratory many experiments have been tried on calcining and mixing various materials with gypsum, and in physical tests on the plasters and mixtures.

In the summer of 1902, on the invitation of Mr. Alfred C. Lane, State Geologist of Michigan, I spent nearly two months in the field on a study of Michigan gypsum. This work has been followed by careful chemical and physical tests and by a search of American and European literature for additional information.

In collecting the accounts of the gypsum industry from abroad and from this country, I wish to express my obligation to the scientists who have so kindly sent me data and references. These persons are mentioned by name in the chapters devoted to these subjects.

In my Michigan work I wish to express my appreciation of the favors extended to me by the State Geologist, Mr. Lane, who has placed in my hands, records, books, and notes, relating to the subject in hand, and who has in other ways aided me in this investigation.

I am indebted to Mr. Frank Leverett for the account of glacial geology of the Grand Rapids area, and to the report of Mr. W. M. Gregory for the geology of the Alabaster district. I am especially indebted to the officers of the various gypsum companies who have extended to me every courtesy and have cheerfully furnished me with desired information about their mines and mills. Without this co-operation this report would have been of little value.

The officers of the U. S. Gypsum Company have placed in my hands samples of their products for physical and chemical examination, and have furnished me with information about the development and history of the Michigan gypsum industry before and since the time they secured

so large a control. Most of the localities studied are reached by the Pere Marquette railroad, and I wish to return my thanks to Mr. S. T. Crapo, General Manager, for favors extended to me in this work.

Many of the men prominent in the early history of the gypsum industry in Michigan, have passed away and others have advanced in age. The effort was made to secure and record the information about the early history as nearly first hand as possible. In a short time this would have been impossible, and some of these men have died since this work was started.

It is hoped that this volume may be of some service to the gypsum development in this State, and Michigan is to be congratulated on the history and development of this plaster industry. It will continue to develop in the future.

Topeka, Kansas, June, 1903.

CHAPTER I.

INTRODUCTION.

§ 1. Mineralogical Properties of Gypsum.

Gypsum is a mineral composed of sulphate of lime and water, with the chemical formula $CaSO_4 + 2H_2O$. It is one of the softest minerals and in the old Mohs' scale of hardness it stands number 2 in the scale of 10. It has a specific gravity of 2.32, i. e. weighs about 2.320 ounces to the cubic foot.

The specific gravity of gypsum is shown in comparison with limestone, cement, etc., in the following table taken from Mr. Wilder's report:[1]

Limestone	2.46 to 2.84
Quicklime	2.30 to 3.18
Lime mortar	1.64 to 1.86
Gypsum	2.30 to 2.40
Calcined gypsum	1.81
Portland cement	2.72 to 3.05
Anhydrite	2.89 to 2.98

I have no data on specific gravity of the set plaster, but I believe it will be nearly the same as the gypsum rock. I tried to determine the expansion in setting or the relation of dry plaster to the set plaster, in volume. I could detect no expansion by direct measurement and by filling a thin glass bottle with mixed plaster and permitting it to set in this case the bottle was not broken or cracked. I could not run in a colored liquid around the plaster so apparently it did not shrink.[2]

Gypsum crystallizes in the monoclinic crystal system in the form of plates or prisms with pyramidal terminations. The relative lengths of the crystal axes are represented by the formula 0.6891:1:0.4156, while the angle of the inclined axis to the vertical is 81° 5′. Twin or united crystals, as shown in Figure 3, are very common, where the crystals are twinned on the orthopinacoidal face.

[1]Iowa Geol. Survey. Vol. XII. p. 139; 1901.
[2]But see Chapter XI, §6.

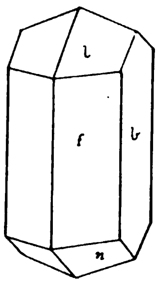


FIG. 1.

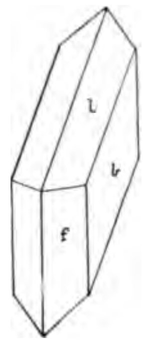


FIG. 2.

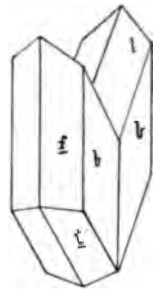


FIG. 3.

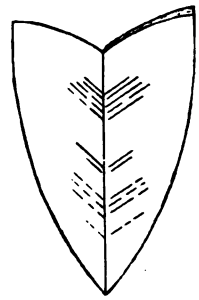


FIG. 4.

Figures 1 to 4: 1. One form of gypsum crystal.
2. Common form of gypsum crystal.
3. Twinned gypsum crystal.
4. Twinned gypsum crystal with rounded edges.

The typical forms of the crystals are shown in Figures 1 and 2. The cleavage is almost perfect on the face *b*, which explains the plate-like characters of gypsum found in the rocks. Cleavage very often takes place on the face *n* cutting across the first cleavage. The faces of the twin crystals are sometimes rounded as shown in Figure 4. This is especially characteristic of the many crystals near Mont-martre near Paris, so such crystals are sometimes called Mont-martre twins. Perfect gypsum crystals are rather rare in Michigan rocks.

Mr. A. M. Apted of Grand Rapids has an extensive collection of Michigan gypsum crystals at his house. "White flint seams" stand in relief on weathering. The flakes of selenite sometimes cover as much as one inch on the gypsum. The veins of salt are about one-fourth inch thick. He has a fine specimen of calcite crystal with gypsum from Hope, Kansas. This gypsum is very hard and fine grained. The Deadwood gypsum is fine grained. The Fort Dodge gypsum is coarse and has marked characteristic brown and white lead. The Sandusky gypsum is fine grained and flinty. Some specimens show a red gypsum with white combs of gypsum crystals between, but there is a fine gypsum crystal standing alone with a peculiar kink showing the flexibility of the same.

There are two types of crystals; one prismatic m. b. with oblique termination as illustrated, and others with nearly square ends, and this face nearly perpendicular to the prism (e) has a much duller lustre. There is one specimen of gypsum with geode cavities of crystals in the middle but this is said to be rare. From Syracuse, N. Y. we have red gypsum crystals.

Solubility of Gypsum.

Gypsum is only slightly soluble in water, as shown in the following table of Marignac:[1]

[1] Annales de Chimie. Paris, 5th series, vol. 1, pp. 274 to 281, quoted by Chatard, Seventh Annual U. S. Geol. Survey, and verified by the writer.

Temperature.	One part gypsum dissolves in—	One part anhydrous sulphate lime dissolves in—
At 32° F. = 0° C.	415 parts of water	525 parts of water
At 64.5° F. = 18° C.	386 " " "	488 " " "
At 75.2° F. = 24° C.	378 " " "	479 " " "
At 89.6° F. = 32° C.	371 " " "	470 " " "
At 100.4° F. = 38° C.	368 " " "	466 " " "
At 105.8° F. = 41° C.	370 " " "	468 " " "
At 127.4° F. = 53° C.	375 " " "	474 " " "
At 161.6° F. = 72° C.	391 " " "	495 " " "
At 186.8° F. = 86° C.	417 " " "	528 " " "
At 212 ° F. = 100° C.	452 " " "	572 " " "

The maximum solubility is found at 38° C. or 100° F., and then only one part of gypsum dissolves in 368 parts of water. while about 40 parts of common salt will dissolve in 100 parts of water at a temeprature of 60° F.

§ 2. Early History.

Gypsum has been used in various ways from very early times. On account of the soft lustre given to the light as it is passed through the transparent plates of gypsum, the ancient people were reminded of the light from the moon, and so named this variety of gypsum *selenite* from a Greek word σελήνη = the moon. Selenite was regarded by these people as the most delicate variety of alabaster and was used by the wealthy in their palaces as windows.

The walls of the old temple of Fortuna Seia[1] were constructed of stone supposed to be compact gypsum and "the interior though without windows was rendered sufficiently light by rays transmitted through its semi-pellucid walls."

At Florence the gypsum of Volterra was made into vases in which lamps were placed, throwing a soft light over the room. In Arabia the building of Arsoffa Emii, supposed to be an old monastery, is constructed of gypsum, "and when the sun shines on it, the walls give such a lustre that they dazzle the eyes, but the softness of the stone and redness of the mortar have conspired to make it a very ruinous pile at present, though of no great antiquity; the stone having split and mouldered away in the wall and the foundation has failed in many places." (Rees in 1814.)

The writings of Theophrastus and Pliny show that the Greeks were familiar with the uses of plaster, made by calcining the gypsum stone, in making casts. They state that the first plaster casts were made by Lysistratus of Sicyon, who was a brother of the famous sculptor Lysippus. He made first a cast in plaster from the object and from this obtained a second one in wax. Rhaecas and Theodorus of Samos worked by the same method, but the art appears to have attracted very little attention and was soon neglected and in course of time forgotten. It was revived by Verocchio (1422-1488) and others, when the method of casting

[1]Rees' Cyclopedia of Arts, Sciences, and Literature: 1814.

in plaster proved of great service in obtaining copies of the specimens of ancient sculpture which were then discovered.

The compact variety of gypsum, or alabaster, is frequently referred to in ancient writings; though this word is so often used to describe the stalactitic carbonate of lime. that it is not possible to tell from the meagre descriptions whether the alabaster mentioned is the sulphate or carbonate of lime.

The derivation of the word is a much disputed question. According to some writers it is derived from two Greek words, α = without, and λά βαι = handles, referring to a box without handles made from this material and used to hold perfume. This derivation is said to be inconsistent with the rules of formation of the Greek language, and the derivation was probably given long after the word itself was coined. A similar derivation, more consistent with the Greek rules, gives an origin based on physical character, from α, = not and λαμ βάνω (Latin *Capio*) = to take, so named because the rock is smooth and slippery and difficult to handle. Another writer gives an Arabic origin, from *al batstratron*, meaning a white stone. A derivation which seems more probable connects the word with the town Alabastron, in Egypt, where in early times there was a manufactory of urns, vases, and other ornaments made from the gypsum stone found in the mountains near by.

The alabaster used in these early days came mainly from Syria and upper Egypt. The statues and basso relievos of the mausoleum of the Connêtable de Lesdiguières, of the cathedral of Gap, were made of alabaster taken from Boscadon near Embrun, in the High Alps. The Encyclopedia Perthensis, written in 1816. states that:

"There is a church in Florence still illuminated, instead of by panes of glass, by slabs of alabaster near fifteen feet high each of which forms a single window through which light is conveyed."

Gypsum rock was not very thoroughly examined or investigated until the last century. Chambers' Dictionary of Arts and Sciences in 1753 gives the following summary of the knowledge concerning this mineral down to that time:

"Gypsum in natural history, the name of a class of minerals, the characters of which are these: They are composed of small flat particles irregularly arranged, and giving the whole mass something of the appearance of the softer marbles; they are bright, glassy, and in a small degree transparent; not flexible nor elastic, nor giving fire with steel, nor fermenting with or dissoluble in acid menstruum, and calcine very readily in the fire. Of this class of bodies there are two orders. The first order is of *gypsums* which are of a firm, compact texture and considerably hard. The second, of those which are of a lax or loose texture and are accordingly soft and crumbly."

§ 3. Consolidation of Gypsum Companies.

The gypsum industry has shown a marked increase in recent years in the United States. In 1902 the total production was 816,478 tons, with a value of $2,089,341 according to the U. S. Geological Survey. Michigan holds first rank among the states in the total amount of gypsum quarried, and probably first rank in value at the present time.

Consolidation seems to be the order of the age, and the gypsum industry has proved no exception to the rule. When it was announced in 1901 that a two million dollar trust was being organized to control the gypsum industry, many people for the first time began to wonder what the gypsum industry really was; but very little serious consideration was given to the announcement of consolidation.

On February 1st, 1902, the United States Gypsum Company was incorporated with Mr. B. W. McCausland, president; O. B. English, vice president; Emil Durr, treasurer; with a capitalization of $7,500,000. These men were already well known plaster men in Michigan. Mr. McCausland had been president of the Alabaster company, Mr. Durr was associated with the Grandville mill, Mr. English had built a new and modern mill at Grand Rapids.

This company soon obtained control of eighteen plaster mills, thirteen mixing plants, and three chemical mills distributed as follows: Three mills in Michigan, two mills and two mixing plants in Ohio, one mixing plant in Pennsylvania, two mills and two mixing plants in New York, one mixing plant in Indiana, one mill and two mixing plants with two chemical mills in Illinois, two mixing plants in Wisconsin, two mixing plants and one chemical mill in Minnesota, six plaster mills in Iowa, one mixing plant and a retarder factory in Nebraska, three plaster mills in Kansas, and one mill in Oklahoma. This company has its main offices in Chicago and branch offices in eight other leading cities.

In the historical sketch which follows, the attempt has been made to show the development of the plaster industry in the State, from the time of the early crude mills in the 60's designed for the manufacture of land plaster so highly valued by the farmers of that time, to the present mills equipped with modern machinery and to the present mines equipped in some cases with electrical appliances for convenient and rapid handling of the rock.

There has been progress in the Michigan plaster industry though it has been slow, especially in the earlier mills. There are few places where so many experiments have been tried for improving the methods of manufacture of gypsum plasters, as have been performed in this State in the past years. Many of these early experiments proved to be failures, but out of the failures came suggestions which have proved valuable. From the records, Michigan seems to have been the first place where continuous calciners were constructed. but these early attempts proved to be

failures; and therefore it is difficult to convince a Michigan plaster man that such continuous kilns of the present time represent improvements. In Michigan the plaster calcining kettle was developed in its present form, though the first design came from New York. In this State we find further attempts to improve the plan of the kettle by adding more flues, 40 in one type, but the use of these kettles with numerous flues has been confined mainly to one plant.

The manufacture of prepared sanded plasters is said to have started in Michigan, but other states now give a larger production. The largest gypsum quarry in the country is seen at Alabaster, Michigan, and there are few quarries that equal this one in facilities for work and in the purity of the rock.

The first plaster combination in this country was formed in Michigan by the Michigan plaster men and was known as the Michigan and Ohio Plaster Association. The largest combination of plaster interests was started by Michigan plaster men and is known as the United States Gypsum Company.

The invention of gypsum wall paint which made the finished wall a work of art, and which has attracted favorable attention in all parts of this country and abroad, was made by Mr. M. V. Church of Grand Rapids and named Alabastine.

Michigan has been one of the pioneer states in the American gypsum industry, and to-day it is one of the foremost states in a well developed gypsum industry. It is fitting then that a monograph on this subject describing not only the local deposits and local history, but also the industry as a whole in the United States and in the foreign countries, should be issued by the State Survey of Michigan.

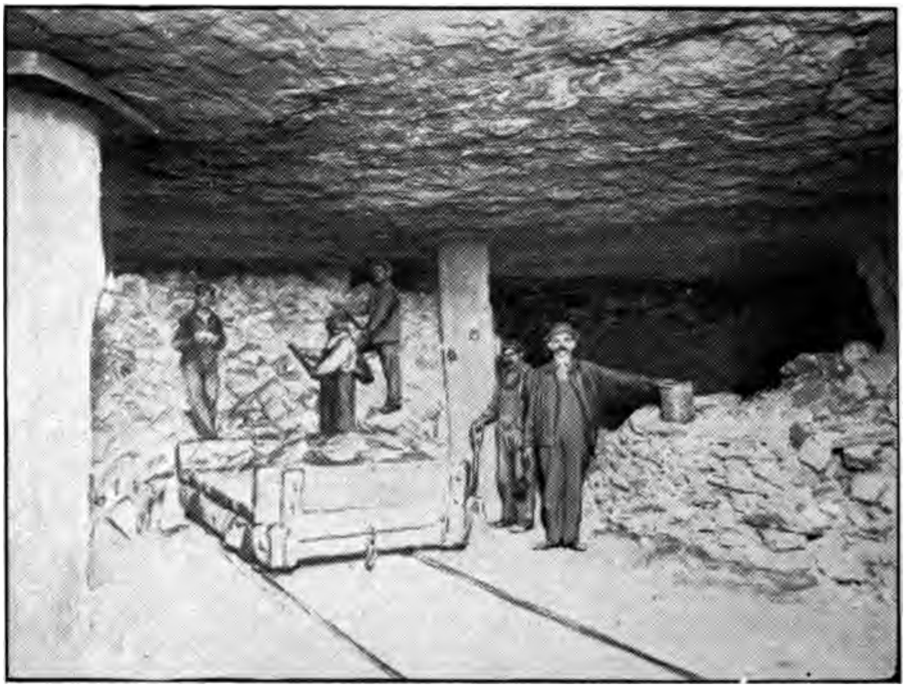
§ 4. Brief Summary of the Report.

The distribution of gypsum throughout the world is described in the next chapter and the methods of manufacture in foreign countries are given in brief form, and a similar discussion of the distribution of gypsum in the United States is given, including the interesting secondary deposits of gypsum earth found in the southwest. A theory of origin is given.

The third chapter gives a historical resumé of the development of the gypsum industry in Michigan from the year 1827 to the present, and shows the gradual development of the industry through the experimental work of the pioneer plaster men of the State.

In chapter four, the geology and topography of the Michigan Lower Carboniferous gypsum deposits are taken up in detail. The deposits correspond to the Osage (Augusta) of the Mississippi valley. This formation outcrops around the border of the interior coal basin of Michigan, but it is covered over much of the area by the drift. The geology and topography of the drift are described in a paper by Mr. Frank Leverett.

A. PLASTER CREEK AND ALABASTINE MILL.



B. MINING GYPSUM.

Chapter five gives a brief account of the St. Ignace gypsum deposits on the Upper Peninsula, which are not of commercial importance at the present time. They differ from the other Michigan deposits in being of the uppermost Silurian or Salina age.

Chapter six is devoted to the study of records of wells drilled in the State, which shows the distribution of the Michigan Group below the surface. In this chapter an attempt is made to estimate the quantity of available gypsum in Michigan, giving 138,000,000 tons, which at the present rate of production in the United States would supply the whole country for over 170 years. See Appendix A.

A description of the Michigan mines and mills is given in the seventh chapter. There are seven mills now in operation, and two abandoned for the present, and one, the Powers mill, which was in operation when this report was first started, but was burned in the spring of 1903.

In the Grand Rapids area the gypsum is found in two layers, an upper six foot ledge, and the lower twelve foot which is the one now worked at the quarries. The rock is mined in open quarry, in hillside slope entries, and by shafts. At Alabaster the gypsum ledge runs from 18 to 22 feet in thickness. The Michigan mills are usually frame buildings, well constructed, and arranged so as to facilitate the rapid handling of the product, and they can produce a thousand tons of plaster a day if worked at their capacity.

The process of manufacture is described in the eighth chapter, and is practically the same at all the mills. It consists of crushing the rock in jaw crushers, buhr stones, and emery mills, and calcining in 8 or 10 foot vertical iron kettles. The products made are land plaster, dental plaster, plaster of Paris, retarded wall plaster, and Alabastine wall paint.

This chapter includes a discussion of retarders, giving their composition and effects on the plaster, which are not injurious when good retarders are used in small quantities. The set of plaster is shown to be due to the formation of a crystal network, and the different theories advanced to explain the causes of the set of plaster are given.

Chapter nine gives analyses of gypsum from the different parts of the United States and the world, and discusses especially the chemical composition of Michigan gypsum which contains 94.7 to 98.3 per cent of lime sulphate plus water, or gypsum, leaving but a small per cent of impurities. The analyses of finished plaster are also given showing the changes resulting from calcination.

The tenth chapter deals with a rather new phase of gypsum examination, and one often neglected in a discussion of gypsum, that of the physical examination of gypsum plasters. The chapter devotes special attention to the tensile, compression, and adhesion tests of the plasters. The work is based on a large series of tests extending over a period of two

years, and should be of practical value to the gypsum companies of the State and of interest to all users of, and workers in, gypsum products.

In the eleventh chapter the various theories of origin of gypsum are discussed and the conclusion reached that the Michigan gypsum is a deposit through evaporation of an enclosed basin formed as a gulf in the old Osage sea and finally cut off from that gulf. The conditions then present are regarded as analogous to the present Caspian Sea.

The twelfth chapter treats of gypsum as a fertilizer and should be of interest to the farmers of the State, as it includes a summary of experiences and theories collected from various sources over the world. This is a much disputed subject and the conclusions reached are rather against the value of gypsum as a fertilizer under ordinary circumstances.

In chapter thirteen the uses of calcined and uncalcined gypsum are enumerated and described. The variety of uses of gypsum is somewhat a matter of surprise to persons who have an acquaintance with but a few of them.

Appendix A consists of a series of tables of statistics of gypsum production in the world and in the United States. It is seen from these tables that Michigan has produced since the beginning of the industry 2,587,656 tons of gypsum with a value of $9,528,805, one-half of this amount was used as land plaster and one-half was calcined. The greatest production was in 1902 when 240,227 tons were mined of which 69 per cent was calcined. Michigan has held for some years first rank among the states of the Union in the production of gypsum.

Appendix B gives references including a bibliography of all the works so far found by the writer which treat in any way of gypsum. Most of these works were consulted in the preparation of this volume.

CHAPTER II.

GENERAL DISTRIBUTION OF GYPSUM.

§ 1. England.

The principal deposits of gypsum of commercial importance in England[1] are near Fauld in Staffordshire, Chellaston in Derbyshire, Kingstone-on-Soar, and Newark in Nottinghamshire, Carlisle in Cumberland, Kirkby Thore in Westmoreland, and Netherfield in Sussex. In addition gypsum is found near Watchet in Somersetshire, near Penarth in South Wales, at Swanage, near Alston in Cumberland, at Shotover Hill in Oxfordshire, and in Cheshire.

The rock occurs in nodules and in lenticular and irregular masses up to fifteen feet in thickness, but as a rule not in regular beds of large extent. In age the principal deposits of British gypsum occur in Keuper marls (Trias), but in Cumberland and Westmoreland the mineral occurs at a lower horizon in the Red Beds (Permian). The Sussex gypsum is found in Purbeck strata (Jurassic).

The gypsum in the Purbeck strata in Sussex was discovered in making the Sub-Wealden boring which was commenced in 1872. The gypsum in the Triassic formations has been worked for many generations.

The purest British gypsum is a snow white granular or crystalline rock. It is usually colored by oxide of iron producing brown irregular veins and markings. Some of the gypsum occurs in nodules of pink color. The origin of the gypsum in England is generally ascribed to precipitation from inland bodies of salt water.

Uses.

The purest crystalline gypsum known as alabaster is largely worked in England as an ornamental stone, especially for interior ecclesiastical work, and for inlaid panels in halls and on staircases. It is ground to flour and calcined into plaster of Paris, and then is used for ceilings, walls, mouldings, and is a principal constituent in many patent plasters and artificial marbles. It is used to a limited extent in paper and glass manufacture, and also in the preparation of certain pigments and pharmaceutical products. The largest gypsum mine in England was the

[1]The writer is indebted to Prof. John W. Judd and Mr. Budler of London for most of the information concerning the gypsum of England.

Chellaston plaster mine in Derbyshire, but in 1890 the production ceased. The largest plaster mill in England is the Vale of Belvoir and Newark-on-Trent Plaster Company mill at Newark-on-Trent.

The amount of gypsum quarried in 1900 in England was as follows:

	Tons.	Value.
Cumberland	41,794	£8,359
Derby	10,289	4,630
Nottingham	77,492	32,208
Stafford	47,736	15,700
Somerset	5,110	1,265
Sussex	17,768	5,730
Westmoreland	7,849	1,750
Total	208,038	£69,642

§ 2. Australia.[1]

Gypsum occurs in layers in the Rolling Downs formation (Lower Cretaceous) in Western Queensland in conjunction with conglomerates, sandstones, shales, and gypseous marls. As a rule these beds are thin and the gypsum is generally massive in structure and is milky white in color. It is found sometimes crystallized as selenite.

Gypsum also occurs in the Desert Sandstone formation (Upper Cretaceous) where it occurs as layers in sandstone and generally with fibrous structure. It is often observed in close proximity to the opal deposits of this formation. Gypsum has been found in small quantities in a few other localities in Queensland.

§ 3. India.[2]

In India, gypsum of economic importance is of rare occurrence. A small supply comes from southern India. In several of the outside regions it occurs in inexhaustible quantity but often difficult to reach, so that most of the gypsum used is imported.

Madras: Trichinopoli District.—According to Mr. H. Blanford[3] this mineral is abundant in many parts of the Cretaceous rocks of this district. It is generally somewhat impure, occurring in concretionary masses and plates. It would answer when made into plaster of Paris for taking moulds, but not for casts where whiteness is required. It seldom occurs in sufficient quantity to be worth collecting, though plates of pure selenite are obtainable. It is most abundant in the Utatur beds, especially in the belemnite clays to the east of Utatur, and in the unfossiliferous clay to the northeast of Maravuttur.

Chingleput District.—In the clayey estuarine beds to the north of Madras,[4] concretionary masses of gypsum and crystals of selenite occur,

[1]The information in this section was obtained through Wm. H. Rands, Government Gologist for Queensland.
[2]The following is Mr Ball's account of the deposits of India furnished to the writer by Dr. J. Le Griesbach, Director of the Geological Survey of India.
[3]Memoirs Geol. Survey of India, Vol. IV. p. 214.
[4] " " " " " Vol. X. p. 132.

but not in any abundance. According to Mr. Foote, supplies for making plaster of Paris for use in the Schools of Art at Madras have, however, been obtained from this source.

Nellore District.—In the eastern coastal districts of which Nellore is one. crystals of greater purity than those found near Madras are said to occur. It is considered by Mr. Foote[1] that they might be collected in the neighborhood of the canal and forwarded to Madras, where the consumption is increasing.

Bombay District.—Gypsum in the form of selenite is found in small quantities in the marine deposits about Bombay and in Kattywar, and it is stated to occur in parts of the Deccan in connection with deposits of salt. But the principal sources of gypsum in this Presidency were situated in Cutch and Sind.

Cutch.—The following is Mr. Wayne's[2] account of the distribution of gypsum in Cutch: Large quantities occur in shales belonging to the Jurassic, Sub-Nummulitic and Tertiary groups; the most highly gypsiferous being those of the Sub-Nummulitic band. The mineral is generally translucent; and clean blocks, several inches in diameter, may be found weathered out on the surface of the ground.

Although much of it might be obtained without any great trouble, it does not appear to be utilized except to a slight extent by goldsmiths, who are said to use it in a powdered state for polishing their wares.

Sind.—Several writers on the geology of Sind allude to the occurrence of gypsum. According to Mr. W. T. Blanford[3] it is found in some abundance near the top of the Gaj beds of the Kirthar range; the beds of it are not unfrequently three or four feet thick. Two such beds of different degrees of purity are exposed in the section of the banks of the Gaj river, and similar beds occur not infrequently further in the north.

Dr. Buist[4] has called attention to the fact that in Sind the art of making plaster of Paris was known to the natives, and that it was employed in casting lattices and open work screens for the top of doors, etc., where a free circulation of air was desirable; the dryness of the climate in Sind protects it from injury on exposure.

Baluchistan.—It is probable that in the continuation of the Sind beds northwards into Baluchistan similar beds of gypsum will be found to exist. That it actually does exist is known, but details are not yet available.

Afghanistan.—Near Kandahar gypsum is obtained from lenticular masses and veins in the Gaj formation and in the post-Pliocene gravels. Capt. Hutton states that the plaster is largely used in the buildings of that section. It was first discovered in the time of Ahmed Shah, who

[1] Memoirs Geol. Survey of India, Vol. XVI. p 104.
[2] " " " " " Vol. IX. p. 90
[3] " " " " " Vol XVII. p 195.
[4] Trans. Bomb. Geol. Soc'y. (1852), Vol. X. p. 229.

considered it so valuable that he caused public prayers and thanksgivings to be offered up, and celebrated the event with feasting and the distribution of charity.

Punjab.—Gypsum is found in Kalabagh and in the Khasor range, but it is not at the present time utilized. Both here and also at Mari and Sardi, quartz prisms with pyramidal terminations are found in great abundance in the gypsum and they go by the name of Mari diamonds.

Kohat District.—In this district gypsum is very abundant. It might be obtained by open quarrying in any quantity, but it is not worked. The crops. especially the wheat, which are raised on the soil resting on the gypsum at Spina are said to be finer than those in any other part of the country.

Salt Range.—In those portions of these districts which include the salt range, gypsum occurs in enormous quantities associated with the salt marls of the Silurian or the Pre-Silurian age. Some of the most compact varieties near Sardi are manufactured into plates and small ornamental articles.

Spiti.—Very considerable deposits of gypsum are found in the Spiti valley. The origin is traced to the ordinary chemical reaction between iron pyrites and carbonate of lime.

North-West Provinces.—In this district, gypsum in lumps and veins is found in the rocks of Tertiary age and older rocks. In origin, this gypsum is secondary and it is used to some extent for interior decoration.

In the Kamaun and Garhwal districts gypsum is found in considerable amount and is used for plaster in a number of places.

§ 4. Tasmania.[1]

Gypsum does not occur in Tasmania in deposits of economic importance. It occurs in lumps and veins in Tertiary clays near Launceston, also in benches in serpentine rock associated with talc at Trial Harbor. It also occurs in Permo-Carboniferous limestone, but none of these occurrences are of any economic importance.

§ 5. Canada.[2]

In the Salina formation of the Upper Silurian in Canada occur extensive beds of gypsum, which are not continuous for long distances, but appear as detached dome like masses sometimes one-fourth of a mile long. The gypsum is interstratified with dolomite, and is often separated by beds of it. The workable beds are seen on the Grand River twelve or fourteen miles above its mouth and are traced to the town of Paris.

[1]Note furnished the writer by W H. Twelvetrees, Government Geologist at Launceston.
[2]Geology of Canada, 1863, pp. 347, 762.
Minerals of Nova Scotia, Gilpin, 1901, pp. 55–57.
The Mineral Wealth of Canada, Wilmott, 1897, pp. 105-111.

On the left bank of the river near the town of Cayuga is a large deposit of gypsum covering about 60 acres.

Gypsum is also found in this same area near York, in Indiana, and Mt. Healy, where the ledge is three and one-half feet thick. The gypsum at York is seven feet thick but separated into several layers, the thickest of which is two feet. The gypsum is traced from here two miles to Seneca and it is found twenty miles north near Brantford.

Near Paris there are two beds of gypsum nine feet in all. The gypsum formation outcrop extends from the Niagara river to the Saugeen on Lake Huron, a distance of 150 miles, but most of the mines are within a distance of 35 miles on the Grand river extending from Cayuga to Paris.

Large deposits of gypsum are found on the Magdalen Islands in strata of Carboniferous age and are shipped into Canada.

In Nova Scotia the gypsum beds vary from a few inches to a hundred feet in thickness and are found in the Lower Carboniferous formation, possibly nearly equivalent to the Lower Grand Rapids or Michigan series of Michigan. The chief localities where the mineral is worked are, Windsor, Cheverie, Maitland, Walton, Hantsport. Wallace, Mabou, Antigonish, Lennox, St. Ann's, and Big Harbor. Gypsum is shipped in the crude state to the United States mainly from the Windsor district and some from Cape Breton.

Gypsum is found in large amount in New Brunswick. It is quarried at the Albert mines, where the rock is 60 feet thick, and it is calcined at the large works at Hillsborough.

Gypsum occurs in northern Manitoba in two beds, 22 and 10 feet thick, and northwest along the Mackenzie river; also, in the Salmon river, in British Columbia.

In 1902 the Canadian production of gypsum was 332,045 tons.

§ 6. Cyprus.[1]

Gypsum deposits are found in many parts of the Island of Cyprus, but the deposits worked are near Larnaca on the east and Limasol on the west coasts. The stone at Larnaca is said to be the best, and there are large deposits at both places. The stone appears on the surface for miles around these two places, and it is quarried by the natives and hauled in carts to the factories. There are two factories at Limasol which have been in operation for the past five years, and one factory at Larnaca erected about fifteen years ago. These mills cannot supply the demand for the plaster. About 200 tons are sent annually to Turkey and 7,000 tons to Egypt.

The plaster kilns are built of fire-proof stone in the form of a small room eight or ten feet square, with arches made of the stone two or three feet high, and on these arches the gypsum blocks are placed and a fire of

[1]Information furnished by Dr. W. M. Moore of Larnaca, Cyprus.

brush wood is built under the arches. After burning the stone is crushed in mills which have been brought from England and France and operated by steam power.

The plaster is of three grades according to the fineness of the grinding. The color of the plaster is gray and not white. It is used for plaster of Paris and for building purposes.

§ 7. France.[1]

The French gypsum in the neighborhood of Paris has given the name to the calcined product the world over, so that at the present time plaster of Paris is a world product as well as a French one. As the Paris region is apparently the home of this industry, it may be of especial interest to examine the geology and the methods of working of the gypsum deposits of that region.

The gypsum quarries are located at Mont-martre, Pantin, Belleville, Sannois, and Enghien, in the Tertiary deposits of the Paris basin made famous by the paleontological studies of Cuvier.

The varieties of this gypsum are designated as,

le gypse filamenteux................ confusedly crystalline.
le gypse feuilleté................... selenite.
le faux alabâtre.................... alabastrite.
le sulfate de chaux calcarifère....... ordinary gypsum.

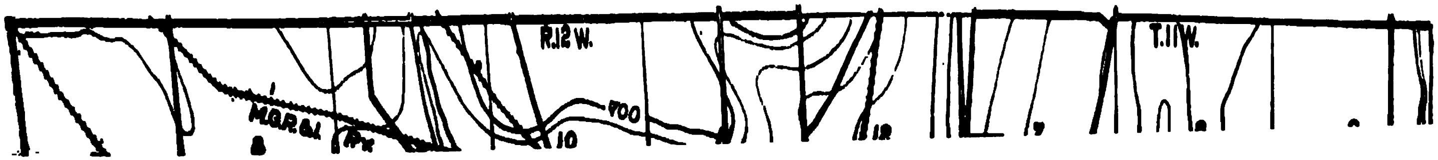
There are three main strata of gypsum in the Paris basin. The lowest is composed of beds of gypsum with a large proportion of selenite, in this mass there are five beds with a total thickness of seven feet seven inches. This stratum is seldom worked because it makes a poorer quality of plaster and is difficult to mine.

The second and third strata are separated by beds of marl and are about five feet in thickness, but vary in different parts of the basin. At Mont-martre the second stratum is 33 feet and has eight workable beds. One of these beds at Belleville called the "big vein" (le gros banc) is often used for artistic plasters.

The thickness of the gypsum series at Mont-martre is 160 feet, and at Sannois it is nearly 180 feet, at Enghien it is about 100 feet. A section near Paris shows the following order of rock strata:[2]

8. First layer of gypsum or principal mass of gypsum.
7. Marl.
6. Marl with kidneys of gypsum.
5. Second layer of gypsum with marl (containing shells of Cerithus).
4. Yellow marl (with shells of *Lucina inornata*).
3. Third layer of gypsum.
2. Marl (with fossils of *Pholadomya ludensis*).
1. Fourth mass of gypsum.

[1]For sources of this information see under France in Bibliographic list.
[2]Lapparent, Geologie, p. 1163.


R.12 W.
T.11 W.
700
10
12
M.G.R.&I.

The first layer of gypsum is the most constant, most extensive, and usually the thickest (reaches 65 feet at Mont-martre) in the Paris area. It marks the horizon of mammalian fossils described by Cuvier and it is characterized by a prismatic parting which has given the name of the tall pillars (hauts piliers).

The Paris gypsum is remarkable for its high percentage of lime carbonate amounting to 10 and 12 per cent. Many have ascribed the high quality of French plaster to the presence of this material, and it has given support to a theory of peculiar origin of the gypsum, namely, that the gypsum is due "purely to a fresh water deposit produced by a river whose waters are highly charged with lime sulphate, somewhat like the La Frume Salso in Sicily described by Lyell" (Burnell). According to Lapparent, the origin is lacustrine and the gypsum was formed in lagoons or sheets of water near the shore of the ocean, and represents a direct precipitation of gypsum and not a transformation of any beds of lime.

The gypsum is quarried in open cuts, by shafts, and by driving galleries into the hillside. The last is the most common method and is followed at the Mont-martre, Triel and Belleville quarries.

Method of Calcining Gypsum in France.

There is a marked contrast in the methods of burning gypsum in France and in the United States. Most of the American rock is calcined in kettles by direct heat, and even where rotary cylindrical kilns are used, the heat is direct. The French plaster manufacturers have invented a variety of kilns and methods which are held in high favor by the companies using them.

One of the common types of kilns is described as a much simpler arrangement than the American kettle and would seem to represent a more crude method. A series of arches (see Figure 5[a]) are constructed out of gypsum blocks and supported on piers of the same material. These arches are about one foot eight inches wide and two feet four inches high. On these are placed large blocks of gypsum then smaller and smaller blocks, until the kiln is filled to a height of about 13 feet. The whole kiln is covered by a shed roof, and spaces are left between the blocks to give a draft. The arches are filled with wood and a hot fire maintained until the lower blocks begin to glow red hot, which requires about 10 hours, then a slow fire is kept for 10 to 12 hours. The lower rock over the arches is overburned and the upper rock is underburned, but a mixture of the whole gives a fairly uniform plaster. Such a kiln holds 70 to 75 tons of rock and the plaster is removed in from two to three days, and requires 1,200 fagots of wood which formerly cost twelve to fifteen cents per hundred. These fagots now cost 40 cents a hundred, and many kilns now use part coal in the form of briquettes.

In the province of Saône and Loire, coal is used for calcining and it requires about 1,120 kilogrammes of coal to calcine 25,000 kilogrammes of plaster. In the manufacture of land plaster the gypsum is often burned in lime kilns to render the rock friable and easily broken.

Improved Types of Kilns in France.

The kiln described above is said to be used more commonly than any other, but a number of plaster works are now using improved kilns where the heat is usually indirect. The Brisson kiln used at Pantin is analogous to a gas furnace in construction. It has eight retorts, each holding two hectoliters of gypsum, heated by a single fire, attended by a single workman, and yielding a very white plaster. The plaster made in the rough kilns described above is usually gray in color, and it was formerly considered by plasterers in France that gray plasters were always superior in quality to white, so for a long time any process making a white plaster was looked upon with suspicion.

Kiln of Ramdohr.

In the continuous kiln of Ramdohr, there are a series of retorts placed in vertical rows opening above. These retorts are oval in section and made of separate pieces united with cement collars. The retort is heated by direct fire in the upper two-thirds of its length, and the lower third measuring one metre serves to partially cool the plaster. The removal of the finished plaster is effected by the aid of three conical valves below moved by a crank and pinion. One man can handle a battery of seven to nine retorts. Each retort calcines in twenty-four hours six charges of six hectoliters, or 36 hectoliters, and consumes 600 kilogrammes of lignite or 200 kilogrammes of coal. (One hectolitre = 150 kilogrammes, or 330 pounds.)

Continuous Gypsum Kiln of Hanctin.

This method differs from all those so far described in that the gypsum is pulverized before the calcining. The furnace is composed of a tubular bundle lightly inclined, all bound together and moved by a shaft with a moderate rotation. The flame circles around these tubes and the gypsum in descending slowly comes under the influence of the heat. The powdered gypsum is thrown into a hopper over each tube. By regulating the length of the tubes, and the inclination, a uniform calcination is said to be secured. In some of the Paris plants the heat for calcination of the gypsum is secured by forming gas in a generator and conducting this to the center of the gypsum furnace.

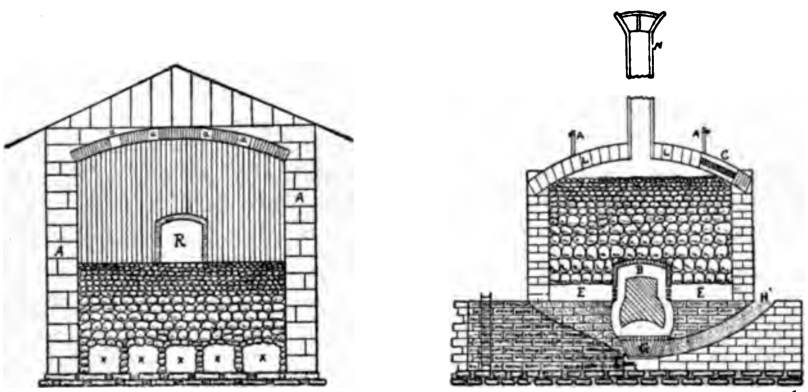
Calcining Plaster by Vapor of Superheated Water.

In this system of Violette, there is a generator or heater for water vapor connected with a serpentine metal coil. The gypsum rock is

placed in a double receptacle in a wall of masonry. It is oval in form with two openings opposite each other which can be hermetically sealed and which serve to charge and discharge the plaster. A thermometer is used to determine the temperature of the entering vapor.

The vapor formed in the generator circulates in the serpentine coil and heated to the proper temperature enters the first receptacle, reaching all parts of the rock and calcines it gradually and equally. The vapor then passes into the second receptacle and acts upon the rock, and then escapes into the air carrying all the moisture of the gypsum, on account of the high temperature of the vapor. The process depends upon the principle that superheated water will absorb water.

M. Tested Beauregard has modified this system and injects upon a hot surface in a specially constructed kettle, a thread of water which is



a *b*

Fig. 5. Gypsum kiln: (a) common type.
(b) Dumesnil kiln, used in France.

changed to vapor. This vapor is then heated in a powerful heating retort to as elevated a temperature as required for calcination, which is regulated in a constant manner. These methods have certain theoretical advantages and certain practical difficulties. The apparatus used is simple in construction and small volumes of water are used. The quality and beauty of the finished product are of the best. On the other hand it is difficult to keep the temperature at 200° C., as usually required and there is a tendency of the vapor to drop in temperature and to condense in the midst of the material to be dried.

Dumesnil Kiln.

Another variety of kiln held in high favor in France is the Dumesnil kiln shown in Figure 5° This has a central fire pit (G) with a fire chamber (B) above, which is connected with radiating flues (EE) con-

structed of the larger fragments of the gypsum rock. Above these flues the stone is arranged in layers containing smaller and still smaller fragments toward the top. In the arch (L) forming the top of the kiln are flues (AAN) controlled by dampers. The gypsum is charged through the opening at C and removed through a door at the side. Coal is used as fuel and is added at H. The ash pit is located at I. The kiln is 20 feet in diameter and 13 feet in height to the top of the arch. It will hold (35 cubic metres) 1,200 cubic feet and it is burned in twelve hours with a fire of fagots and a little less with coal. The method is said to be economical, and the plaster is uniform in quality.

§ 8. Germany.

Hartz Mountains District.[1]

In the southern part of the Hartz, gypsum is found near the top of the Zechstein formation (Permian) from Osterode, Sterna, and Sachsa on the west to Mohrungen and Obersdorf near Sangerhausen on the east, a distance of six miles. In places it forms mountains as Katzenstein near Ostrode, Kohnstein at Ilfeld.

The rock is almost compact, white in color, or in places colored slightly gray through the presence of bituminous matter. It has been formed through anhydrite altered by inflowing water.

The gypsum industry centers at Ellrich, Walkenried, and Osterode, also in Tettenborn, Niedersachsweisen. At Sangerhausen, some 16,500 double wagon loads of gypsum are worked annually. In Thuringia near the Hartz, gypsum layers in the Bunter sandstein of the Trias are worked at Frankenhausen; and in the Keuper of the Trias at Walschleben, Elsleben, and Gispeileben north of Erfurt.

Mode of Calcining.

The gypsum is ground on mill stones, each a set of three of 600 mm. (23.4 inches) diameter. The middle stone revolves while the other two remain stationary. It takes from five to six H. P. and grinds about 1,200 kilogrammes (2,640 pounds) per day. The plaster is calcined in iron kettles set in masonry and the material is kept in motion by revolving stirrers. (See Figure 6.) At Osterode one mill uses a round iron vessel as a muffle kiln for burning the plaster.

In Ellrich and Walkenried some double shaft ovens four metres (13 feet) high and one and one-half metres (nearly 5 feet) in diameter are used. The fuel and gypsum are placed in these shafts in alternate layers and covered with a shed roof. As soon as the plaster is completely calcined it is drawn out below and more material added to the top.

For 100 years the Hartz gypsum plasters have been used in cellar walls,

[1] Die Gypsindustrie im Harz. M. Gary, Thonindustrie, 1899, Vol. XXIII, pp 1079-1082

gates, etc., the plaster mixed with small river pebbles, and some of these arches with ten metres (32 feet) span are still solid.

Other German Localities.

Gypsum is found near Frienwalde and Muskau, at Sperenberg, Luneberg, Seegeberg in Holstein, Rudersdorf near Berlin, in Lowenberg in Silesia, and in the northern border of the Thuringian forest as at Rheinhardtsbrunnen.

In some of the primitive mills the rock is broken in stamp mills. The stamps are made of maple or oak with an iron shoe at the bottom giving a length of 2.825 metres (9.1 feet). These fall in a trough of wood with

Fig. 6. German plaster kiln.

an iron grate bottom. It is ground finer in a roller machine in which heavy rollers move over a pan somewhat like an American dry-pan brick machine. These rolls make 50 revolutions per minute and are 314 mm. (1.25 feet) in diameter and 260 mm. (10 inches) in breadth. In some mills a jaw crusher is used not very unlike the type used in the Michigan mills, and the fine grinding is then accomplished by means of mill stones. These are about 40 inches in diameter and make 120 to 130 revolutions per minute. They require four H. P. for grinding plaster and five or six H. P. for the unburned gypsum.

Gypsum[1] is found in the Triassic formations of the district of Trêves in the upper valley of the Moselle near the province of Luxemburg. In this region gypsum is found in the Muschelkalk rocks (Trias) near the

[1] From information kindly furnished by Dr. O. Follman, Coblentz.

villages of Igel. Wasserbillig, Oberbillig, and Temmels, and the stratum is nine metres (29 feet) thick.

At Welschbillig the gypsum near Olk is six metres thick and in the same formation of the Muschelkalk are the gypsum layers of Wallendorf in the eastern part of Prussia, 15 metres (about 49 feet) thick. In Westphalia at the Godensdorf the gypsum is four or five metres thick, and at Minden it is three metres (9.7 feet), all of these being in the Muschelkalk. In a number of places gypsum is found in thin seams and layers in the Bunter sandstein of the Triassic formation.

A most excellent account of the process of the manufacture and uses of the gypsum in Germany has recently appeared, and it was written by Prof. Wilder of Iowa in Volume XII of the Iowa Geological reports. Mr. Wilder personally visited the mines and mills. According to this writer the German gypsum industry centers especially in the Hartz mountains near the village of Ellrich, in Thuringia near Possench and Krolpa, and at various towns on the Rhine near the mouth of the Neckar. The three varieties of calcined plaster sold in Germany are: "stuck" gypsum used in plastering walls and for building-blocks or boards and for ornaments and imitation marble; "estrich" gypsum burned at a temperature of 500° C. and used for making a very hard plaster used especially for floors; "porcelain" gypsum used for porcelain ware moulds.

§ 9. Switzerland.[1]

The gypsum of Switzerland is mainly in the Triassic formations. It is found in abundance in the Trias of the Jura and of the Rhine border, also in the Alps. Small deposits occur in the Purbeck (Upper Jura) of the Jura mountain region, and veins of fibrous gypsum are found in the Lower Miocene.

The gypsum varies in thickness in different localities and it is usually white or gray in color. It represents a deposition from concentrated sea water. The chief localities for these gypsum deposits are in the anticlinal valleys of the Bernese and Argovian Jura, Villenne parish of Ollon, in Bex, in the Valois, Cherret, and several other places. There are extensive plaster quarries near Ponterliers.

§ 10. Sweden.

According to Dr. Henrik Santesson, gypsum occurs in Sweden in very small quantity in a few places, but it is of no economic importance. The plaster and gypsum used in that country are imported.

§ 11. Italy.

It has been difficult to collect information concerning the gypsum deposits of Italy. Alabaster is worked at a number of places, the purest is that of the Val di Marmolago near Castellina, 35 miles from Leghorn,

[1] Information furnished by Prof. E. Chuard of Lausanne.

and it is very popular for the manufacture of ornaments. A white wax like variety comes from Volterra and a granitic variety comes from Carrara.

GYPSUM IN THE UNITED STATES.

§ 12. General Remarks.

Gypsum deposits are found in most of the states and territories of this country (see map, Pl. XIII), and are worked in many of them. The industry is small even in some of these areas where the supply is almost unlimited. Sparsely settled districts have small demand for gypsum products, and a number of the largest deposits are located at a distance from the railroads.

The industry is well established in a number of states and it is being started in others. A brief review of some of these districts will now be given. It was hoped that this review would be more nearly complete, but many of the companies refused to give any information about their work or the deposits.

§ 13. New York.

The facts given for New York state are taken mainly from the reports of the State Museum especially by Merrill, Clarke, and Parsons. The gypsum deposits of the state occur in the Salina or higher formations of the Upper Silurian period and occur in regular beds which show that the gypsum was originally deposited from water. Mr. Clarke states in his report that no evidence of gypsum is found east of Madison county, and that toward this eastern limit the gypsum is of a darker and more earthy type, probably due to the presence of carbonaceous matter. The dark variety lies nearer the surface, while the whiter gypsum at the west is generally heavily capped with rock and has less thickness than the other.

Fayetteville.

The quarries at Fayetteville are located about two miles southwest of the village and there are five companies engaged in the work. The Severance quarry has been worked for over 60 years, and it shows the greatest thickness found in the state, 60 feet, and consists of 8 layers 18 inches to 30 feet thick, and the gypsum is overlain by shaley rock. The amount of lime sulphate is greatest in its crystalline layers and least in the brown layers. It runs from 80 to 90 per cent of lime sulphate.

The rock is mined by stripping off the surface shaley layers. Three beds are distinguished in this quarry of which the upper is 30 feet thick and lighter in color. The product is sold to local mills and hauled one and one-half miles to the Erie canal where it is shipped to outside points. The quarry covers three acres and it is estimated to cost twenty-five to thirty cents a ton for mining. The average output is 5,000 tons a year.

Adjoining the Severance quarry are the quarries of the National Wall Plaster Company, where the gypsum is present with the same character as at the other quarry. The area is about five acres and the mill of this company uses the Cummer process of rotary calciners described under the chapter on technology.

East of these quarries there is a fifteen acre tract of gypsum owned by the Adamant Wall Plaster Company. This tract was abandoned for a number of years. Smaller quarries are found in the same section.

Cayuga Plaster Company.

The largest quarries in the state belong to the Cayuga Plaster Co., of Union Springs, four miles west of Cayuga. The original gypsum area was about one mile square on the east shore of Cayuga lake and was opened in 1828. The output is about 10,000 tons of plaster and 5,000 tons of rock gypsum annually.

The gypsum is covered with earth and underlain by limestone. The color of the rock is gray with plates of selenite more or less intermingled. The rock has a maximum thickness of 40 feet with an average of 8 feet of top rock and 8 feet of bottom rock. The gypsum runs about 80.8 per cent lime sulphate. The other quarries in this section are small and have been worked from time to time.

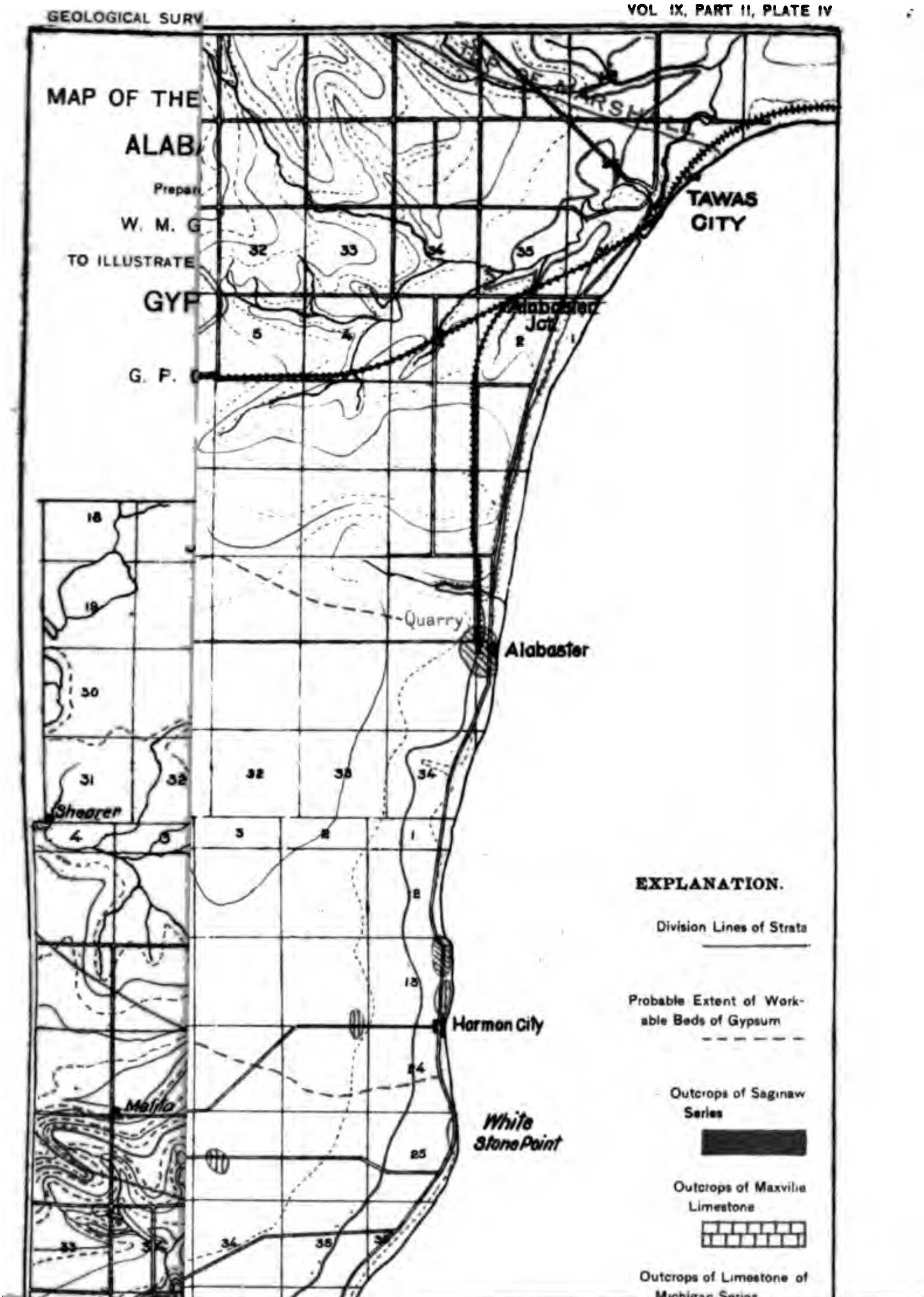
Wheatland Land Plaster Company.

The Wheatland quarry is located about three and one-half miles from Caledonia, and the gypsum occurs in three layers, the middle one being the best. The deposit is six feet thick and is worked through a tunnel. The rock is used at the mill near at hand, with a capacity of 40 tons a day. A mile east at Garbuttsville is the mine and the mill of the Lycoming Calcining Company. The rock at this mine is worked through a tunnel 200 feet long and the mill has a capacity of 60 tons in ten hours.

Oakfield Gypsum Deposits.

At Oakfield in Genessee county, there are three companies working the gypsum deposits. The United States Gypsum Co. has the largest mill and operates two mines about 40 feet deep, reaching the gypsum rock which is four feet thick. They ship annually 15,000 tons of rock to the Pittsburg plate glass factories and calcine about 10,000 tons. The gypsum at these mines is of high degree of purity and snow white. Eighty feet below the first bed of gypsum is a second, ten feet thick, not worked. The other companies have five mines, and all use the kettle process of calcining.

The farthest west gypsum worked in New York state is in these Oakfield mines. Drilling, however, shows that under Buffalo at a depth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Harmon City
Melita
White
Stone Point
EXPLANATION.
Division Lines of Strata
Probable Extent of Workable Beds of Gypsum
Outcrops of Saginaw Series
Outcrops of Maxville Limestone
Outcrops of Limestone of Michigan Series

of 50 feet there is a deposit of over 25 feet of white gypsum. Attempts were made a number of years ago by the Buffalo Cement Co. to mine this layer by sinking a shaft, but the inflow of water stopped the work and it was abandoned.

Twelve companies are engaged in working the gypsum quarries in New York state.

§ 14. Ohio.

The Ohio gypsum area was visited by the writer in the summer of 1902 and the following notes obtained which were supplemented by reference to the reports of the Ohio Survey. Gypsum is quarried in this state at the single locality near Gypsum station, Ottawa county in the northern part of the state, ten miles west of Sandusky.

The Fletcher mill is equipped with two ten foot kettles and the rock from the quarry is dried in a rotary drier with a daily capacity of 110 tons requiring one-half ton of coke a day. The mill is connected with the mine by an incline track. The gypsum was formerly mined by stripping, but now it is mined through a double entry mine which runs into the hill about 400 feet. A section of the mine shows 16 feet of clay then three feet of shale above the gypsum which runs from five to seven feet thick and rests on four feet of limestone, below which is another stratum of gypsum four feet thick not worked in the mine. The mill was built in 1898 and is now owned by the United States Gypsum Co.. and has a daily capacity of 100 tons. A new company has constructed a shaft one-fourth of a mile east of this quarry and expect to build a mill this summer.

The oldest mill in this state is a couple of miles west of the Fletcher mill and was first built in 1872 by Marsh & Co. though this company was organized in 1846 when they built a mill at Sandusky which was supplied with rock from this locality near Gypsum. In 1885 the plant was doubled in capacity and again doubled in 1890 and now has a daily capacity of 200 tons.

The Marsh quarry was worked for many years in open pit by stripping off the cover, but since 1890 they have secured the gypsum through a tunnel into the hill. They have now constructed a shaft on a new tract to the west of the mill, 46 feet deep, and the stone is hauled from this mine to the mill on an overhead track. The mines are to be worked with electric drills and the rock brought to the surface by an electric hoist.

The gypsum is covered with 24 feet of soil and shale which rests on a three foot gypsum ledge separated from the eight foot vein by one foot of blue limestone. The floor of the quarry is a calcareous shale one foot thick resting on a layer of impure gypsum for or five feet thick. The rock from the quarry is dried in a rotary drier 33 feet long and 6 feet in

diameter and is crushed in a large Champion crusher. There are four eight-foot Butterworth and Lowe calcining kettles. The fine grinding is accomplished by six ordinary buhr mills and the rock flour is reground for certain purposes in a twenty-four inch emery mill. The rock is stored in long sheds with a capacity of 12,000 tons. The rock is white in color and over 96 per cent pure.

The geological age of the deposits is Upper Silurian, Salina, or Lower Helderberg of Orton, a formation with maximum thickness of 700 feet. The gypsum occurs through it at various places, and the mineral is found in most of the deep wells drilled in northern and central Ohio. The gypsum beds, according to Orton, are not even and horizontal, but are found in waves and rolls, whose summits rise five to eight feet above the general level. The main plaster beds are about twelve feet thick and would yield about 50,000 tons to the acre.

No fossils are found in the formation, and Orton regards the origin of the gypsum as due to a deposit from a shallow, land locked and contracting sea during this period. The shallowness of this sea is shown by the sun cracks and wave marks that are well shown in these rocks. The annual production of gypsum in Ohio is over 51,000 tons.

§ 15. Pennsylvania.[1]

In Pennsylvania gypsum occurs in the Lower Helderberg in the seams intermingled with mud veins and the whole series lies just below a drab impure limestone. The origin has been regarded as due to an alteration of the limestone to gypsum through the agency of sulphur spring water, but it occurs at the same point in the geologic column as that of Ohio. The deposits are not of economic importance.

§ 16. Virginia.[2]

The important gypsum deposits in Virginia are found in the southwestern part of the state in the valley of the North Fork of the Holston river in Smyth and Washington counties. The deposits have probably been formed through the evaporation of an enclosed sea basin and they are of Lower Carboniferous age. The rocks are faulted, and the gypsum deposits are found north of the main fault known as the Saltville fault.

The gypsum deposits in Holston Valley area commence three miles west of Chatham Hill where about 300 tons a year are quarried. At Saltville there are several quarries where the gypsum is ground for land plaster or shipped to Glade Springs where it was used in the manufacture of Keene's cement until 1902.

The largest mines are located southeast of Saltville at Plasterco and

[1]Geol. Survey of Penn., Summary Final report, Vol. II, pp. 913-915.

[2]Eckel, Salt and Gypsum Deposits of Southwestern Virginia, U. S. Geol. Survey, Bull. 213, pp. 406-461: 1903. Stevenson, The Salt and Gypsum Deposits of the Holston Valley, Virginia, Proc. Amer. Philos. Soc. Vol. XXII, pp. 154-161: 1884.
Boyd, Resources of Southwest Virginia, pp. 104-108: 1881.

belong to the Buena Vista Plaster Co. The gypsum stratum is 30 feet thick and dips northwest at an angle of 50 degrees and has been mined to a depth of 280 feet. About 11,000 tons of rock are annually quarried. The gypsum is covered by twelve feet of blue clay and soil, and the salt formation is found at a depth of 200 feet.

These eastern and central United States deposits belong to the earlier part of the Paleozoic era of geological time. In the western part of the country the deposits of gypsum belong to the closing part of the Paleozoic and to the Mesozoic time.

§ 17. Iowa.[1]

The gypsum deposits of commercial value in Iowa are found in Webster county in the north central portion of the state, in the vicinity of Fort Dodge. The area underlain by gypsum is given by Wilder, as 60 to 75 square miles with at least 40 square miles available for working. The gypsum area is cut in two by the Des Moines river and large quantities of the gypsum have been removed through erosion. It is estimated that the total amount of gypsum removed up to the present time by mining is about twenty-five acres.

These gypsum deposits were first described by Owen in 1852 and later by Worthen and others. The first mill was erected in 1872 near Fort Dodge, and in 1878 the manufacture of hard wall plaster was commenced. Other mills were erected later and now seven gypsum mills are located in this area with a total capacity of 600 tons of plaster a day.

The gypsum rests on the St. Louis limestone or on the Coal Measure shales. Except near the streams the deposit is covered with drift. The gypsum is regularly stratified in heavy layers ranging from six inches to two feet and separated by thin layers of clay. In thickness the deposit varies from ten to thirty feet. The lower three feet of the series are usually rejected as impure, but the amount of such impurity is not great. The rock is crystalline throughout and its upper surface is quite irregular through water erosion. In composition the rock runs 99 per cent pure in the upper layers.

The gypsum is overlain by red shales conformably, and both lie unconformably on the Coal Measures. The shales are without fossils. The age is given as Permian and the deposit was formed probably in an inland sea connected with the open ocean similar to the Mediterranean sea of the present time.

In the earlier days of the gypsum industry of Iowa, the gypsum was obtained by stripping off the drift cover, one to twenty feet thick, and then quarrying out the rock. At the present time it is obtained by drifting into the deposit along streams or by shafts. Two or three feet are left for a roof and the entries are about nine feet high. The rock is calcined in kettles holding eight or ten tons each.

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[1] Iowa Geological Survey, Volumes III, XII.

§ 18. Kansas.[1]

The Kansas gypsum deposits of economic importance form a belt trending northeast to southwest across the state. The belt of exposed rock varies in width from five miles at the north to twenty-five miles in the central part, and 140 miles near the southern line, with a length of 230 miles.

This area is naturally divided into three districts, from which the important centers of manufacture are named: the northern or Blue Rapids area in Marshall county; the central of Gypsum City area, in Dickinson and Saline counties; and the southern or Medicine Lodge area, in Barber and Comanche counties.

All of these deposits are found in the Permian, the central deposits are at the base of the Upper Permian, and the southern deposits are at the top of the Upper Permian, in the Red Beds.

Gypsum of economic importance is found in two forms in Kansas, rock and gypsum earth. The rock is quarried especially in the northern and southern areas. It has a compact or sugary texture breaking with irregular fracture, and usually white in color or slightly mottled through the presence of clay impurities. The rock in the northern area is eight and one-half to nine feet thick resting on a limestone floor and covered by shales. It is mined through tunnels driven into the hill, though formerly obtained by stripping.

In the central area two companies are mining the gypsum rock through vertical shafts eighty feet deep which reach a 14 to 16 foot stratum. In the southern or Medicine Lodge area, the gypsum reaches its greatest thickness. It here caps the red clay and shale hills as a white rock layer protecting the underlying softer rock and gives a very picturesque topography in the Gypsum Hills country which continues southward into Oklahoma. The base of the hills is a massive red sandstone and above this are 200 feet or more of red shales, clays and some sandstone. At the top is a gypsum layer three to forty feet in thickness.

The gypsum earth deposits are found especially in the central area and were the first deposits of this kind worked in the United States. They are described in another chapter.

At the present time there are three gypsum mills in the northern area which are working the rock. In the central area there are four mills, two using the rock and one using the gypsum earth and one using both rock and earth. In the southern area there are two rock mills. Very little Kansas gypsum is ground for fertilizer, but most is calcined into plaster of Paris or cement wall plaster. The method of manufacture in these mills is practically the same as used in Michigan and the plaster is calcined in kettles. Of the nine mills, four are owned by the United

[1] University Geological Survey, Vol. V.

States Gypsum Co., two by the American Cement Plaster Co., and three by separate companies.

§ 19. Arkansas.[1] (Plate XXIX, location 11.)

At Plaster Bluffs on Little Missouri river in Pike county, and at many other points along the southern boundary of the Trinity formation, there are beds of gypsum and gypsiferous marls of all degrees of purity and excellence, from pure saccharoidal gypsum to that containing from 10 to 20 per cent of gypsum in quantities practically inexhaustible.

The gypsum occurs in strata six inches to six feet in thickness with seams of satin spar, 10 feet in all overlain by 15 feet of gypsiferous sands and marls and 50 feet of Quaternary gravels. The gypsum rests on a sandy lime stratum one foot thick, and below this comes sands, shales, and marls. The gypsum is suitable for the manufacture of plaster of Paris, and the impure gypsiferous marls might be used for fertilizer. At the present time no use is made of this material.

§ 20. Oklahoma. (Plate XXIX, location 15.)

The extensive gypsum deposits of Oklahoma are of Permian age and they are grouped by Gould in his report published by the Oklahoma Survey under four general regions:

1. The Kay county region in the central part of Kay county.
2. The main line of the Gypsum Hills extending from Canadian county northwest through Kingfisher, Blaine, Woods, and Woodward counties to the Kansas line.
3. The second Gypsum Hills extending along a line parallel with the main range and from 50 to 75 miles further southwest, from the Keechi Hills in southeastern Caddo county, northwest through Washita, Custer, and Dewey counties into Woodward and Day counties.
4. The Greer county region occupying the greater part of western Greer county as well as the extreme southeastern corner of Roger Mills county.

In the first region are small deposits of gypsum earth and one plaster mill is located there. In the second, which is the same as the Medicine Lodge Hills in Kansas, the gypsum ledges aggregate 60 to 90 feet in thickness.

In this area is the Okarche mill using secondary gypsum and it is the oldest gypsum mill in the territory. The features of topography and relations of the gypsum to the red shales and clays are the same as in the southern Kansas area.

The third area is to the west of the main line of the Gypsum Hills and at a higher geological level. The formations in this range of hills extend from Woodward county to Comanche and run nearly parallel to

[1] Arkansas Geological Survey Vol 1, pp. 119, 241, 257: 1888.

the range of hills forming the second area, and 25 to 50 miles west. The gypsum in these hills is not usually found in continuous ledges. A single ledge will in a short distance appear in several ledges. Gypsum ledges run a short distance and then disappear.

Instead of the gypsum capping ledges and making steep hills as in the preceding area, it appears on the surface in the form of rounded knolls or mounds. The width of the gypsum outcrops east and west varies from a few miles to thirty. The thickness runs from 10 to 50 feet, and the rock is about 93 per cent pure.

In the fourth or Greer county area, the gypsum seems to be at about the same geological level as in the third area. In Greer and Roger Mills counties, there are five well marked gypsum ledges. Along the north fork of the Red River in Roger Mills county, the bluff runs for 10 miles, 150 to 200 feet high, and is composed of red clay with four ledges of massive white gypsum, which will reach a total thickness of 70 feet.

There are extensive deposits of gypsum in Greer county which appear in ledges in ravines in the northern part of the county, but the gypsum appears at the surface in very few places in the level country of the southern part of this county. Mr. Gould has estimated the area of gypsum in this region to be 650 square miles with a thickness of 35 to 50 feet. He further estimates the quantity of gypsum in Oklahoma to be 125,800,000,000 tons.

There are four gypsum mills in operation in Oklahoma. The Ruby Stucco Plaster Co. mill is located in north central Blaine county four miles west of Ferguson. The hill near the mill shows three ledges of gypsum with a thickness of 35 feet. The mill was erected in 1901 and has a daily capacity of 150 tons.

The American Cement Plaster Co. mill is located at Watonga in Blaine county and the rock is hauled three miles by rail to the mill which has a daily capacity of 75 tons.

The Okarche mill near Okarche uses the secondary gypsum earth. The Blackwell Cement Co. mill is near Peckham in Kay county and was built in 1899, and has a daily capacity of 100 tons made from the gypsum earth.

§ 21. Texas. (Plate XXIX, location 16.)

The first account of the gypsum deposits in Texas is probably to be found in Marcy's Red River Report of 1852[1] in which he states that near the source of that river the waters had a peculiar taste, received in flowing for 100 miles over a gypsum formation, which he described as follows:

"I have traced this gypsum belt from the Canadian river in a southwest direction to near the Rio Grande in New Mexico. It is about fifty

[1]Pages 5?, 91, 172, 173.

miles wide on the Canadian, and is embraced within the 99° and 100° meridians of west longitude. Wherever I have met with this gypsum I have observed all the varieties from common plaster of Paris to pure selenite. I regard this gypsum belt as a very prominent and striking feature in the geology of the country. From its uniformity and extent, I do not think there is a more perfect and beautiful formation of the kind known. I have myself traced it about 350 miles, and it probably extends much farther . . . The only deposits known to me as more extensive are those in South America, described by Darwin in his geology of South America. Very probably the ancient igneous agency in the Wichita mountains, and along a line southerly to the Rio Grande may have been concerned with the production of the gypseous deposit of the same region."

In Texas, Dumble[1] reports valuable gypsum deposits in the lower Comanche series of Burnet county. In the Permian the beds are numerous and often of considerable thickness. The clay is traversed in every direction by seams of fibrous gypsum, varying in thickness from paper like seams to 10 feet, while the compact gypsum reaches 25 feet.

The valuable deposits of northern and western Texas, Dumble believes were deposited in an arm of the sea cut off from the old Permian ocean. The rock is used for plaster of Paris, wall plaster, and fertilizer. The fertility of the river valleys is regarded as due in part to the fact that the rivers have their sources in the gypsum beds.

The plaster industry of Texas at the present time centers in the region around Quanah in the northern part of the state. Both rock and earth are found here, but the earth deposits are the ones usually worked. The first company to locate in this area was the Acme Cement Plaster Co., of St. Louis. They have eight eight-foot kettles producing about 300 tons of plaster daily and manufacture all grades of plaster, including plaster of Paris, wall plaster, and Keene's cement. They use earth and rock in their work. The American Cement Plaster Co., of Kansas, also has a mill in this section which is using the gypsum earth. The earth deposits near Quanah are said to cover nearly a thousand acres.

§ 22. Colorado.[2]

The important gypsum producing center in Colorado is in Laramie county where there is one mill located five miles west of Loveland. The gypsum stratum is found in a valley of erosion one-half mile wide in the midst of mountain folds of Jura-Trias age, and the basin is hollowed out of an anticlinal fold. The main quarry shows a gypsum face 250 feet long, 28 feet high at the center, and sloping to 7 feet at the edges. The gypsum is compact, gray in color, over 99 per cent pure, and is found in two beds, one over the other, having a dip of 15 degrees to the north.

[1]First Annual Report, pp. 123, 188, 193: Second Report, pp. 455, 456, 700.
[2]Lakes in Mines and Minerals, Vol. 20, p. 227; 1899.
Lee in Stone, Vol. 21, July, 1900.

The cover is not over 18 feet, and the gypsum rests on a variegated chocolate limestone.

The deposit is owned and worked by the Consolidated Plaster Co. Their mill has a capacity of 40 tons in 10 hours and uses six ton kettles. They manufacture plaster of Paris, dental plaster, and cement wall plaster.

§ 23. Wyoming.[1] (Plate XXIX, location 17.)

There are a number of gypsum deposits in Wyoming, varying in composition from pure crystal to earth gypsum. At Red Buttes plaster of Paris and wall plaster of fine quality have been made since 1889. The Consolidated Company has been engaged in the work at this place since 1897.

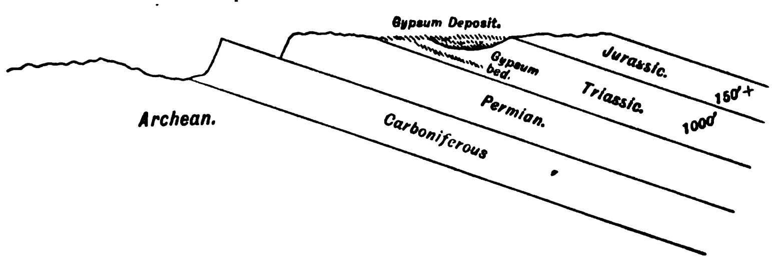

Figure 7. Geological section of Wyoming gypsum deposit.

A second locality of plaster manufacture is near Laramie, where a deposit of 180 acres of secondary gypsum is worked by the Standard Cement Plaster Co., now owned by the Acme Cement Plaster Co., of St. Louis. This plant was erected in 1896.

The gypsum in Wyoming occurs in the "Red Beds" of the Triassic formation. The thickest stratum is near the bottom of the formation above the sandstone and limestone of the Permian and Carboniferous. (See Figure 7.)

The Red Buttes gypsum is in the same formation and the gypsum outcrop may be found at a number of places along the eastern side of the Laramie Plains within a half mile of the limestone and sandstone exposures which form the western slope of the Laramie Mountains.

The sand and lime have washed down from these exposures and are mixed with disintegrated gypsum and deposited in depressions of the plains forming numerous beds of gypsum earth.

The Laramie secondary gypsum has an average depth of 9 feet, 7 feet of this is pure gypsite resting on a five inch red layer and below this is a foot or more of white gypsum earth resting on gravel and red clay. This gypsum earth used in the manufacture of plaster is very fine in texture and is scraped up and calcined in five ton kettles in about

[1] Slosson in Agricultural College Report for 1900.
Knight in personal letter.

ALABASTINE PLASTER COMPANY QUARRY, NEAR GRAND RAPIDS

three hours. The earth has a small proportion of soda in it which is thought to make a stronger plaster.

§ 24. Nevada.[1] (Plate XXIX, locations 25 and 26.)

In northwestern Nevada there are two localities where gypsum is found in large quantities. One is in the Virginia, and the other in the Humboldt range of mountains.

The Virginia range runs north and south some eight to sixteen miles east of the California-Nevada boundary. It is composed throughout the greater part of its extent of Cenozoic volcanics. South of Virginia City the older rocks of the "Bed rock" series are exposed. This series consists mainly of granitoid rocks with disconnected included masses of older strata much metamorphosed. In one of these areas of metamorphic rocks, six and one-half miles south of Virginia City on the Virginia and Truckee railroad is a mass of gypsum which lies in a thick bed almost vertical, and is finely granular, white in color. The roof and floor are formed of light colored limestone. The greatest width or thickness of the gypsum along the surface is about 450 feet, the south side is abruptly cut off by diorite rock.

The gypsum mass runs north for 200 yards with its maximum thickness, then it narrows down and is continued north for half a mile in disconnected lenses. The gypsum through erosion now rests in a depression and much of it has been washed down an eastward ravine where it is mixed with earth forming gypsiferous alluvial deposits.

The rock is removed from cuts on the west side and hauled to Empire on the Carson river, where it is calcined. The rock contains over 90 per cent gypsum, with a considerable amount of lime carbonate.

In origin, the gypsum is thought to be an original part of the stratigraphic series of limestones and quartzites, and formed by precipitation from saline water. All the evidence at hand seems to be opposed to an origin of gypsum through the alteration of the limestone.

In age the gypsum belongs to the series of older rocks that were intruded and folded at the time of the post-Jurassic upheaval of the mountains and is unconformable below the Tertiary lavas. The gypsum is either Triassic or Jurassic and probably the former.

Lovelock Deposit. (*Loc. 25.*)

The Humboldt mountains form a range about the middle part of northwestern Nevada, 80 to 90 miles east of the California-Nevada boundary. In the southern or Humboldt Lake group of these mountains is found the Lovelock gypsum deposit. The rocks of this range are divided into the Bed rock and the Superadjacent series. The former consists of Trias and Jurassic sediments somewhat metamorphosed,

[1]From notes furnished by Dr. Louderbach of the University of Nevada.

folded, and faulted. These are overlaid unconformably by the Superadjacent series made up of Cenozoic volcanics.

The gypsum deposit lies on the west flank of the northern part of the Humboldt Lake range interstratified in the sedimentary series, some six miles northeast of the town of Lovelock on the Central Pacific railroad. The deposit is mainly a grayish white granular mass of rock and quite free from foreign substances.

The gypsum rock forms the axis of an anticline and is exposed for some three-quarters of a mile, pitching below the surface to the north and south. Further north it is brought to the surface again by faulting in the form of a low syncline. The two branches of its exposed surface can be traced to the Humboldt valley, one-half mile along one exposure, and one mile along the other. The roof is a granular white limestone followed by a black limestone which is fractured and intersected by numerous veinlets of calcite. The floor is a white limestone, and layers of limestone occur through the mass.

The deposit of gypsum is a stratum of the Bed rock series, and all evidence seems to show it is an original deposit from some arm of the sea and is probably middle Triassic in age. Chemically the rock contains 95 to 98 per cent of gypsum.

The gypsum was opened in quarry some years ago and then abandoned on account of the expense of transportation. Recently a company has been organized to develop the Lovelock gypsum and ship it into California.

§ 25. California.[1] (Plate XXIX, locations 28, 29, 30.)

The grinding of gypsum rock into land plaster for fertilizing purposes has been carried on at a number of places in California, where deposits of varying thickness and quality have been opened. In 1892, and for some years afterward, land plaster was made at Coalinga from a ten foot stratum and the plaster was used to a considerable extent in the rich fruit belt at Tulare and Fresno counties. In various parts of Los Angeles, Riverside and Santa Barbara counties, gypsum deposits in Tertiary clays have been used for land plaster.

The manufacture of plaster of Paris in the state in the past seems, in many cases, to have resulted in failure of the companies engaged in the work, partly on account of the selection of the poor quality of rock, and partly on account of the lack of skilled calciners. While there are large deposits of gypsum rock found at numerous places north and south, through the Sierra Nevada and Coast Range mountains, most of the material so far tested seems to be too impure for plaster of Paris, making a dark plaster.

The pioneer in the plaster of Paris industry in California was Mr.

[1]This account was prepared by the writer for the Eng. & Min. Journal and published in Vol. 71, No. 23, June 8, 1901.

John Lucas, who came to the state in 1865, after a number of years experience as calciner for the Phoenix Plaster Co. of New York City, one of the leading old time companies. Mr. Lucas experimented with various deposits of gypsum and finally selected a deposit near San Luis Obispo, the rock from which was brought to San Francisco and burned in an ordinary gypsum kettle into the so called Golden Gate plaster of Paris. The business was continued by his sons until about a year ago, when the mill was burned. Of late years the gypsum rock was shipped from San Marcos Island in the Gulf of California, nearly 1,500 miles away. This island is 7 miles long and 3 miles wide, with 280 feet of gypsum exposed over a large portion of it. The rock is a cream white in color, compact, of a high degree of purity and makes an excellent plaster.

Gypsum cement plaster is made near Los Angeles at Palmdale, 62 miles from Los Angeles, where the Alpine Plaster Co. has been engaged in this line of work for 15 years. The company owns a deposit of 240 acres, which has been worked to a depth of 10 and 20 feet and averages 95 per cent gypsum. The finished plaster is faster setting than eastern plasters, reaching its set in 45 minutes. Another company known as the Fire Pulp Plaster Co., of Los Angeles, is engaged in the manufacture of a special kind of wall plaster made by mixing plaster of Paris with clay and asbestos fibre, so as to combine fire proof qualities, slow set, and durability. The company is now constructing their own calcining plant.

On account of the mild climate in California, gypsum plasters can be used for outside work as well as on interior walls. Some of the earlier attempts at the manufacture of hard plasters proved to be failures. Such failures have retarded the introduction of these plasters in this State, and there has been a strong prejudice in favor of ordinary lime plasters. The larger buildings are now plastered with hard plasters, and this industry is attracting much attention from eastern plaster men. The manufacture of hard gypsum plasters will without doubt be a very important industry in California in the next few years.

§ 26. Other Districts.

Gypsum deposits are found in several other states and territories in the western part of the United States. The Oregon Plaster Co. operated a small gypsum mill near Huntington, Oregon, for a number of years, and it is reported that the plant has recently been sold to the United States Gypsum Co. (Location 24.)

In Utah deposits are described at a number of places to the south and south-west of Salt Lake. The Nephi Plaster and Manufacturing Co. operated a mill at Nephi. In New Mexico the gypsum is said to occur in very large areas, and both rock and gypsum earth are found. A mill is in operation near the southern part of the territory.

In the Black Hills of South Dakota the Sturgis Plaster and Stucco Co. have operated a small mill, and Mr. Powers of Grand Rapids, Michigan, built a small mill in this same region. (Location 31.)

SECONDARY GYPSUM DEPOSITS—(GYPSITE).

§ 27. Earthy Gypsum, Distribution of.

In the State of Michigan, gypsum is found only in the rock form, and no deposits of earthy gypsum of economic importance are known to exist. Such deposits have been described in Europe: in Germany under the name of Gypserde, Himmels' mehl; in Sweden, as Himmels mjol; in Russia, Gipsowaya muka. These deposits are loose, dust like particles of yellow or gray color, and are found in Saxony near Neustadt, in Bohemia near Frankenhausen, also in Norway, and near Paris. Its origin in these regions is ascribed to the solution of gypsum in water, and it is more abundant in wet than in dry seasons. At Frankenhausen it was observed on the top of a gypsum mountain, as a superficial stratum of about one and a half feet thickness, unconsolidated, and still containing water. Its main use in these areas is a fertilizer and as white-wash.

In the United States gypsum earth is found and worked at a number of localities west of the Mississippi river. The plaster made from such material is darker in color than that made from the gypsum rock, but it is held in high favor by the plasterers in those sections, and by many it is regarded as more desirable.

Deposits of gypsum earth are now worked in Kansas, Oklahoma, Texas, and Wyoming. The material is locally called "stucco," "gypsum earth," and "gypsite." It is a granular earth found often in low swampy ground, dark colored in place, but on drying it assumes a light ash-gray color. It is soft, incoherent, so that it is readily shoveled into cars, and it is ready for calcining with less labor and expense than is required in working the solid rock.

§ 28. Kansas.

The first deposits of this earth were worked in Kansas, where the material was discovered in the spring of 1873 near Gypsum City in the central part of the state. In 1889 the Saline County Plaster Co. was organized and built a mill to calcine this material. The property was afterwards sold to the Acme Cement Plaster Co., which soon became prominent in developing this and other deposits in the southwest. The Gypsum City mill furnished 7,000 tons of plaster made from gypsum earth for the World's Fair buildings at Chicago. The deposit covers an area of 12 acres, and lies close to the surface with little or no cover, and it is in a small creek valley. The maximum thickness of the earth is 17 feet with an average of 8 feet. Strong springs break through the deposit on the east side, and the top of the earth is 20 feet above the

water in the creek. Rock gypsum is found in borings 20 feet below the top of the earth, but there is no trace of gypsum rock above.

The Agatite earth deposit near Dillon and 14 miles east of the last locality covered 40 acres in a swampy area near another small creek. Its greatest thickness is 18 feet and the earth is covered to a slight depth with soil. Gypsum rock outcrops at the same level a quarter of a mile away. This deposit has been abandoned, and the mill moved to Texas.

Another deposit is worked to the south of Dillon varying in depth from 2 to 8 feet, and gypsum rock is found above and below it. Near the bottom of this gypsum earth, in this deposit and another further south, recent shells and bones have been found. Seven miles south of the Agatite deposit another area was worked for a number of years and was similar in its characters to the other deposits of this area. An area of about 60 acres of gypsum earth was discovered and worked in north central Kansas at Longford in Clay county, and in south central part of the state at Burns and Mulvane two deposits were opened.

The Kansas gypsum earth deposits are found in low swampy ground associated with water. They have a limited surface extent and depth. At the present time only three mills are calcining this material, and one of these uses rock gypsum with the earth.

§ 29. Oklahoma and Indian Territory.

The deposits of gypsum earth as well as gypsum rock are wide spread in Oklahoma and they have attracted much attention. The various new lines of railroad have disclosed their presence and have given the opportunity for their development. While the deposits are large, the amount of manufactured product is small at the present time.

A small mill was in operation for a number of years at Marlow, Indian Territory, but the deposit of earth at this point was small and the mill has been abandoned.

At Okarche, Oklahoma, the Oklahoma Cement Plaster Co. has the oldest mill in the Territory. It is a two kettled frame mill with a capacity of 80 tons of plaster a day, sold under the name of O. K. They began their work on a three-acre gray earth deposit which was three feet in thickness resting on three feet of red earth. The company owns a number of these small deposits within a few miles of the mill. One and one-half miles west of the mill are two deposits, 13 and 40 acres in extent, and of a variable thickness.

Chemical analysis shows the gray earth to be much purer than the red earth below.

	Gray earth.	Red earth.	O. K. plaster.
Insoluble matter	7.98	22.54	13.29
Iron oxide	0.27	0.82	0.71
Alumina oxide	0.23	1.54	
Magnesia carbonate	0.24	0.51	0.91
Lime sulphate	71.70	57.21	73.67
Water	18.68	14.37	5.78
Carbonic oxide	1.14	3.16	3.10
Total	100.24	100.15	97.46

Ten miles west of Okarche on the north bank of the Canadian river, are extensive deposits of gypsum earth distributed over an area of 200 acres ranging in depth from 6 to 20 feet.

The only other mill in Oklahoma using gypsum earth is the Kay county mill owned by the Blackwell Cement Co. It is a two kettle mill with a capacity of 100 tons a day.

§ 30. Texas (location 16 and 33).

In the northern part of Texas, near Quanah and Acme on the Denver and Fort Worth railroad, are very extensive deposits of gypsum earth reported as the largest in the United States. These are now worked by the Acme Cement Plaster Co., and by the American Cement Plaster Co.

§ 31. Wyoming.[1]

One of the members of the company which developed the Dillon, Kansas gypsum earth deposit, discovered similar deposits near Laramie, Wyoming, and in 1896 organized the Laramie Cement Plaster Co., which erected a 150 ton mill (location 17).

The gypsum earth has an average depth of 9 feet, 7 of which are worked. The deposits are found in depressions in the Triassic sandstone. These rocks outcrop for a distance of over 50 miles along the west flank of the Laramie mountains and the gypsum deposits are known to exist for over one-half of this distance.

According to Prof. Knight, the gypsum earth has come from beds of gypsum, limestone, and sandstone, that lie higher up along the slope of the mountains. The composition of the earth is shown by the following analysis:

[1] 10th Annual Report of University of Wyoming, pp. 1-18 : 1900. Also letter to writer from Prof. Wilbur Knight.

	Laramie earth.	Red Buttes earth.
Lime sulphate	70.08	64.22
Lime carbonate	8.36	15.74
Silica	5.62	4.50
Iron oxide and alumina	0.64	1.26
Water	8.88	14.00
Sodium sulphate	3.25	......
Magnesium sulphate	3.72	......
Total	99.55	99.73

§ 32. Microscopical Examination of Gypsum Earth.

Under the microscope the gypsum earth shows considerable uniformity in character, as shown in Figure 31. The earth is seen to consist of a mass of small, angular gypsum crystals of varying size. Perfect crystals are found, but most of the crystals have the terminations somewhat rounded by solution. They are not transported crystals, but they have clearly crystallized in place. Mingled with the gypsum crystals are often small quartz crystals. A considerable amount of poorly crystallized calcite is present, and also traces of organic material.

§ 33. Chemistry of Gypsum Earth.

South of Dillon. Kansas, at the works of the Etna Cement Plaster Co. the rock and gypsum earth are both found and show the following composition:

	Rock.	Earth.
Silica and insoluble matter	1.18	3.18
Iron and aluminum oxides	0.15	0.95
Magnesium carbonate	0.52	0.33
Calcium carbonate	0.36	6.18
Calcium sulphate	78.04	69.70
Water	20.00	19.44
Total	100.25	99.78

A comparison of these analyses shows that the earthy variety contains more impurities, as silica, iron, and alumina, and lime carbonate, and a lower percentage of calcium sulphate, than the rock gypsum.

In the Medicine Lodge Valley in Kansas, the rock gypsum 10 to 20 feet in thickness is covered near Springvale by a deposit of red gypsum earth. Between the two, is a porous, fibrous, brittle, white gypsum, evidently due to the alteration of the white compact rock below. Samples of these were collected and analyzed for the writer at the University of Kansas, under the direction of Prof. E. H. S. Bailey.

	Solid rock.	Porous rock.	Red earth.
Silica and insoluble matter.......	0.29	0.36	41.74
Iron and aluminum oxides.......	0.27	0.30	7.36
Magnesium carbonate	1.00	0.82	3.09
Calcium carbonate	13.04	6.89	9.21
Calcium sulphate	71.58	73.35	29.32
Water	18.46	19.38	9.32
Total	104.64	101.10	100.04

The leaching action has removed much of the lime carbonate and evidently part of the magnesia carbonate. The analysis of the earth shows it to be a clay in which the gypsum has been deposited and would perhaps be defined as a gypsiferous clay or shale.

These deposits of gypsum earth generally show higher percentages of the soluble constituents than the rock variety, and a lower percentage of lime sulphate. They are usually higher in silica and insoluble matter.

§ 34. Origin of the Gypsum Earth Deposits.

Gypsum in a form resembling satin spar and in an earthy form is deposited at the present time in dry weather to the extent of nearly one-half inch in a few days by the evaporation of running water along channels near these places. Where the gypsum water of the springs in these deposits is evaporated there remains a crust of gray earthy gypsum resembling very closely the gypsum earth. In Oklahoma I have found stalactites hanging from under a ledge of this earth and clearly formed by precipitation from water, also crusts of the earth in wavy form on the surface of the earth deposit and even on the surface of rock gypsum. By a laboratory experiment with an artifical spring, I have secured material as a deposit from the evaporated water similar to these earths. In this spring arrangement, I placed layers of limestone crushed, clay, and ground gypsum rock and allowed the water to rise from below through the mass. This water flowed into a basin and evaporated slowly in the heat of the room.

A study of the analyses already given shows that the amounts of silica, alumina, and lime carbonate, in the earth deposits are higher than in the rock, which would be expected in a secondary deposit formed in a swamp. The amount of sulphate of lime is lower, so that the earth is not as pure as the rock. The impurity of the earth makes it set more slowly, and so requires less retarder to be added.

The microscopical crystals in this earth are angular and many of them perfect. No masses of gypsum rock are found in the earth, and no fragments of other stone or sand in any amount. The material is quite uniform in size and chemical composition through the whole deposit. If the material was washed from gypsum rocks of higher levels, as some

have maintained, some fragments of gypsum and other rock would certainly be found in some of these deposits.

Spring Theory of Origin.

This theory of origin was first published by the writer in the Kansas report on gypsum. The gypsum earth, then, must have been deposited in these places from solution. If from solution in surface streams, considerable sand and silt would have been carried in, and the chemical composition would vary in different parts of the mass. Further as in most of these areas, no gypsum is over the earth, the streams would have to bring the gypsum from long distances. Some sand, clay, lime carbonate, and organic material are shown by chemical analyses and by the microscope, and these may be due to surface agencies. The water circulating through or near the underlying gypsum rock dissolved a portion of the rock and carried it upward in the springs to the surface of the swamp, where the material was precipitated through evaporation aided by the action of organic matter of the decaying vegetation.

A crust of gypsum would thus be formed and would increase in thickness until all the underlying rock was removed. Now, in some of these deposits borings detect no gypsum below the deposits, but it is found in wells outside at a level below the earth. In such places probably all the gypsum rock adjacent to the gypsum earth area has been removed by solution. Again by building up the swamp floor to a certain height, the rise of the gypsum water springs may have been checked so as to hinder the earth formation. Whatever the cause, the gypsum earth deposit is not now forming over the entire area in any appreciable amount.

The uneven thickness of the deposits, some varying from three to eight feet within the main part of the deposit, shows that the conditions were more favorable at certain points than at others. Possibly these thicker portions were nearer the outlet of stronger springs.

The deposits were formed in a comparatively short period of time. The presence of modern fresh water shells shows that the deposits are recent, formed long after the rock gypsum in the same region.

CHAPTER III.

HISTORY OF THE MICHIGAN GYPSUM INDUSTRY.

§ 1. Early Reports.

In 1825 a mission was started near the present site of the city of Grand Rapids by Rev. Mr. Slater, on the west bank of the river known by the Indians as the Wushtenong (the further district) and called by the whites the Grand river.

In 1827, when General Cass was Governor of the northern territory, an Indian trapper brought to the Slater mission a piece of soft white rock which proved to be gypsum. It had been found near the mouth of Plaster creek, where the existence of such rock was known to the fur traders, but this specimen seemed to be without value, and it was not worked for 14 years after this date.

In 1838, Dr. Douglass Houghton,[1] the State Geologist, was called to Grand Rapids to select a location for a salt well, and in his report described the plaster beds as follows:

"Near Grand Rapids, in Kent county, a bed of gypsum occurs apparently of considerable extent. It is embraced in a gypseous marl, and overlays the limestone before noticed as occurring in this neighborhood. Although the gypsum is only seen upon the surface at two or three points, and the beds have never been opened, I am satisfied, after a somewhat cursory examination, that it exists, covered with a few feet of soil over a considerable district of country, and that it cannot fail to prove a subject of much value to the agricultural interests of this and adjoining parts of the State.

"The gypsum is of the fibrous variety, nearly free from earthy matter, and it is well adapted to nearly all the uses to which this valuable mineral is applied. The bed is distinctly stratified, the layers varying from 12 to 15 inches in thickness, and they are separated from each other by argillaceous matter and earthy gypsum.

"Plaster is also known to exist at several other points in our State, but sufficient examinations have not yet been made to throw any light upon the probable extent of the beds."

As far as can be determined from the old records, Mr. James Clark was the first man to calcine Michigan gypsum. This man, described as an energetic, enterprising, upright man, came from New Jersey as a

[1] Report of State Geologist, p. 11; 1838.

member of the fourteenth white family to Grand Rapids in 1834 and followed his trade as a plasterer. In building a house for that famous early trader of this region, Louis Campau, he wished to add some ornamental stucco mouldings which were to be placed in the gables and around some circular windows. Mr. Clark had heard of the Plaster creek gypsum and secured some of it, which he broke into small pieces with a hammer and had it ground in an old Indian corn mill and then burned the material in a cauldron kettle. On the first attempt at constructing the ornaments the stucco dropped to the ground, but a second attempt was successful and the mouldings remained until the house was destroyed by fire in 1850.

The first inside mouldings and center piece ornaments of plaster were made in a house on the corner of Bronson and Ottawa streets in Grand Rapids by Philip Stewart. In 1845 Daniel Prindle, a man well remembered for his good work and blunt manner of speech, commenced in a small way the manufacture of plaster flower pots and other utensils. Mr. Prindle's work soon changed to the manufacture and setting of inside ornamental work, and in the house of Mr. Rumsey, built 45 years ago, some beautiful pieces of his work still stand firm and fresh.

Plate I gives photographs of some of these pioneers in the industry.

From 1837 to 1841 the gypsum rock was brought from Plaster creek and ground on a small scale in corn mills. The ledge was six inches to eight feet in thickness, and is now seen to be the upper stratum of the Grand Rapids gypsum.

In 1840 Dr. Houghton[1] again called public attention to these deposits, and pointed out the importance of their development in the following words:

"Closely connected with the iron ores of our State in importance, is the subject of calcareous manures. Our citizens are already annually importing from the neighboring states, large quantities of plaster, and this import must have a rapid increase unless means be taken to open the stores which are found within our own State. There is no point now known where gypsum can so readily be obtained, and where it is at the same time so advantageously situated for distribution over the surrounding country, as at the Rapids of the Grand river. Here is an extensive deposit of this important mineral. which in quality is not exceeded by any in our Union, yet thus far it has been entirely neglected. This should not be, for the time has now arrived when it is required for use, and no contingency should be allowed to arise that will cause it any longer to lie dormant."

§ 2. History of the Grand Rapids District South of the River.

In the next year, 1841, the first mill was erected for working the gypsum deposits, by Warren Granger and Daniel Ball near the place

[1]Report of State Geologist for 1840.

where Plaster creek crosses the Grandville road. The land was owned by Mr. Degarmo Jones of Detroit, who had secured 80 acres of this land before 1838, and these men paid Jones rent in plaster delivered by water at Detroit. The mill was equipped with crude grinding apparatus and one run of stone operated by water power from the creek, and with a two barrel cauldron kettle with thick bottom. Under Mr. Rumsey's management, the next year, three cauldron kettles were set in an arch and fired with dry wood. The plaster was stirred by means of a stick with a spud at one end and was removed by shovelling out to one side after the first settling. The manufacture of calcined plaster was a very small part of the work, as most of the rock was ground for land plaster. For this purpose the stone was broken with a hammer and passed through an Indian mill or crusher and ground between mill stones. The land plaster was shipped down the river and around the lakes to Detroit, and from there sold to the neighboring territory. In order to call attention of the farmers of the vicinity to their work, Granger and Ball had posted, in conspicuous places, the following advertisement:

PLASTER! PLASTER!

The subscribers have now completed their Plaster Mill on Plaster Creek, two miles south of this place which is now in operation. They respectfully inform the public that they have on hand at the mill or at either of their stores at Ionia or this place a constant supply. As the quality of the Grand Rapids Plaster is not equalled by any in the United States, they hope to receive a share of patronage as the price is less than it can be obtained for at any place in Michigan. Wheat, Pork, and most kinds of produce received in payment.

Granger & Ball.

Grand Rapids, December 21, 1841.

The first week after the posting of this notice, 40 tons of plaster were sold at the mill at $4.00 per ton. In 1843, Ball sold his interest in the lease to Henry R. Williams, who was the first mayor of Grand Rapids. Mr. Williams started out in the winter with loads of plaster in a sleigh and traded it to the farmers for corn, and kept up this work until the farmers became familiar with use of plaster and soon the demand was beyond the supply and the price reached $5.50 a ton at the mill. In the winter of 1848-9 the mill was running night and day without equalling the demand, so that some teams coming 100 miles were forced to return without a load. In 1852, 60 tons of plaster were hauled every day south by teams, and that year the property passed into the hands of E. B. Morgan & Co., and later was bought by N. L. Avery & Co., the company including Sarell Wood and Benj. B. Church. They changed the water course and moved the mill across the road. This firm dissolved partner-

ship in December, 1857, and was succeeded by Sarell Wood & Co., the company now including Barney Burton, who soon withdrew, and Chas. A. Todd and Abel Thompson took his place.

In 1860, Freeman Godfrey built a mill near the mouth of Plaster creek, three-quarters of a mile from the old mill described, and began the business of mining, manufacturing, and selling plaster. Mr. Godfrey was born in Vermont, September 5th, 1825. He became a railroad contractor in 1845, and, in December, 1856, came to Grand Rapids on the construction work of the Detroit and Milwaukee railroad, which was completed in 1858. He died in Grand Rapids in 1897.

In 1862 he took his brother Silas into partnership under the name of F. Godfrey and Brother. At this time Mr. Godfrey attempted to improve the method of calcining plaster by using two sets of three cylinders for calcining, one placed above the other in each set, all enclosed in brick work with one fire under all. The plaster was carried by means of a fixed screw on the inside of the cylinders from the upper one out to the end and dropped into a hopper and down into the middle cylinder, and out of the opposite end into the hopper of the lower cylinder, and then out of this over a screen into the cooler. He had tried two cylinders, one above the other, and in both groups of two and of six, the cylinders were slowly revolved by the aid of friction rolls on the outside.

In his first attempt with the two cylinders, the lower one was supported on rolls at one end and the other end was driven by a shaft which also operated the upper cylinder. He next changed the arrangement and belted the two together, but the resistance was so great that the belt would slip and the upper cylinder was not turned regularly. In both designs of these cylinders the plaster was not evenly calcined.

The screen used was of perforated metal and the plaster passing through this fell into a double hopper, into the outer part of which water was forced by a plunger pump and came out of the top hot. Mr. Godfrey made his cylinders out of some old boilers which were about three feet in diameter and 16 to 18 feet long. It took three-quarters of an hour for the plaster to pass through the three cylinders. The imperfectly calcined plaster was finally sold to a New York guano works for $1.10 a barrel.

After this somewhat discouraging experience, Mr. Godfrey visited the New York mills, but found the owners very non-communicative about methods of calcining, but a foreman was found who was persuaded to permit Mr. Godfrey to look at the kettles in use at that place. He was able to keep in mind the plan of the kettles, and on his return home had the cylinders removed and built a couple of two flue kettles, and in this way introduced this method into Michigan in 1871. These kettles were made in Grand Rapids, and Mr. Lucas came later from New York, to teach the men how to calcine by this new method. This Mr. Lucas then

departed for California and started the gypsum industry in that state at San Francisco. The early kettles had the bottom set in a cast iron ring and cemented with salt ashes and vinegar cement. At first the ring and bottom were cast in one piece and the shell was necessarily removed in order to repair any break in the bottom. Godfrey then tried a half-inch steel bottom, made in sections, riveted together, but this only lasted about two weeks. Section bottoms are held in favor to-day in some places, and this was probably the first attempt in this direction. The bottom was placed four feet above the grate, but at the present time the distance has been increased to seven feet.

The cracker used at this mill has been followed in plan from that time in all the mills of the State and further west. It was modeled after the old corn cob cracker. In addition to this manufacture of calcined plaster, a more important branch of the work was the manufacture of land plaster. The sales amounted to nearly $500 a day in this line alone, for a considerable period of time.

In 1865 the Godfreys formed a partnership with Amos Rathbone and Geo. H. White, and bought the property of Sarell Wood & Co. for $33,000, changing the name of the old mill company to that of Geo. H. White & Co., and kept the other mill, near the mouth of the creek, under the name of The Florence Mills, owned by F. Godfrey & Co. The two firms were apparently in competition with each other.

Mr. Geo. H. White was a lumber merchant and manufacturer, who was born in Dresden, N. Y., Sept. 9th, 1822, and came to Grand Rapids in 1842. He worked in the store of Amos Rathbone, and in 1865 entered the plaster business. He died September 10th, 1888.

In 1860, Mr. James Rumsey, who had been connected with the management of the old mill, retired from the business and was running a saw mill on a little branch of Plaster creek. His location was one convenient for farmers coming from the south over the Plankville road and from the southwest over the Grandville road. This situation led the plaster company, in 1863, to enter into a contract with him to add plaster grinding machinery to his saw mill and to grind land plaster at a fixed price per ton and which was to be sold at $5.00 a ton. This contract, renewed by the new company, was in force to June 30th, 1873, and over 5,000 tons were sold in this way.

By 1873 the railroads had entered Grand Rapids and the wagon traffic in gypsum over dirt roads had become of little importance. Godfrey and Brother had built docks on Grand river near their works, and large amounts of plaster were shipped by water. The cost of making land plaster in 1865 was 96 cents per ton, of which half represented the cost of quarrying, and half the cost at the mill. In 1873 the cost was $1.25 a ton, and the cost of calcined plaster was $1.46 to $1.80 a ton. The

following table will give an idea of the growth of the land plaster industry at Grand Rapids:

From 1842 to 1850	500 tons a year.
From 1850 to 1860	2,000 tons a year.
From 1860 to 1864	3,000 tons a year.
From 1864 to 1868	8,000 tons a year.
In 1869	12,000 tons a year.
In 1870	12,000 tons a year.

In 1875 the Michigan and Ohio Plaster Association was formed, with Mr. Bullard as President, and later with Mr. Godfrey in that office. The combination included Godfrey and Brother, Geo. H. White & Co., Grand Rapids Plaster Co., Taylor and McReynolds, Grandville Plaster Co., Grand River Plaster Co., Smith, Bullard & Co., Marsh & Co. of Sandusky, Ringland, Vincent & Meservey of Fort Dodge, Iowa. The association was a selling combination only and paid the companies for the land plaster $2.25 a ton, and agreed to sell a certain amount for each company and to proportion the balance of the sales among the companies. The profits to be distributed among the companies in proportion to their output. The association was broken up a few years after, and in the 80's was reorganized and lasted to about 1898.

All was not smooth sailing with the new company of Geo. H. White & Co., and, on July 29th, 1876, Mr. Godfrey went into court for a dissolution of partnership and for the appointment of a receiver of the property, and the case of F. Godfrey & Brother vs. Geo. H. White & Co. lasted in its various windings for twelve years. In September, 1876, under the direction of the receiver, a new quarry was opened near the present Alabastine mill, as the old appeared to be giving out. In 1879 the land of the company, consisting of 425 acres, was divided among the members of the company by the order of the court and the partnership dissolved. The old mill and the adjoining land came into the possession of the Rathbones, and the new firm of A. D. Rathbone and Peck Brothers was organized. The Godfreys kept their land and mill.

Near the quarry which had been opened by the receiver, the Seeley Brothers built a new mill about 1883, which was operated by Mr. M. B. Church, who had invented the Alabastine wall finish. When Church left the company, the Seeleys sold the mill to the Rathbones, who still own and operate the two plants.

§ 3. History of the Grand Rapids District North of the River.

In 1843 Mr. R. E. Butterworth, a cultivated English gentleman, settled on a farm two miles southwest of Grand Rapids and discovered gypsum in plowing a field. Becoming interested he sought for rock in place and discovered it in the neighboring hillside. In 1849 he opened

the stratum and built a small water power mill near the crossroads and ground the rock for land plaster. In 1853 he put down a shaft and carried on his manufacture until 1856, when he sold the business to A. Hovey & Co., including Wm. Hovey and James W. Converse of Boston, receiving for his interests $35,000. Mr. Butterworth then built the machine shops in town and manufactured various kinds of machinery and castings, and made a special feature of gypsum machinery. This foundry is now operated under the name of Butterworth & Lowe, and is prominent in this line of machinery.

Wm. Hovey was born in Concord, Mass., Dec. 3rd, 1812, and followed the trade of a carpenter and joiner. He came to Grand Rapids in 1856 and entered the plaster business. He was general manager and treasurer of the Grand Rapids Plaster Co. to the time of his death, November 21st, 1881.

In 1856, Hovey & Co. built a new mill, known as the Eagle mill, and mined 2,000 tons of rock the first year. In 1860 they incorporated as the Grand Rapids Plaster Co., including Wm. Hovey, Jas. W. Converse, Francis K. Fisher, of Boston, and Charles H. Steward, of New York. The original mill contained cauldron kettles holding 8 to 15 barrels and stirred by a V shaped rake. The kettles were emptied into a large bin cooled by large fans which just cleared the men's heads.

In 1865 two six foot kettles took the place of the old cauldrons and these were changed in 1874 for eight foot kettles of the Godfrey pattern, and in 1892 three ten foot kettles took their place. In 1880 the mill was destroyed by fire, but was soon rebuilt and the same kettles used. In 1890 the Grand Rapids Plaster Co. was reincorporated with some changes in ownership, and in 1901 they bought the neighboring mill now known as the Eagle mill No. 2.

This Eagle mill No. 2 was built in 1869 by Taylor and McReynolds and known as the Emmet mills. It was later sold to a stock company headed by A. D. and F. L. Noble, and on the failure of this company became the property of Noble & Co. until 1891, when it was sold to the Grand Rapids Plaster Co., though run as a separate corporation until the consolidation of 1901.

Two other mills were built and operated for a short time in this same section in the later 60's. The Windsor mill was farther west and the Ingram mill was just west of the Emmet mill on the ground now owned by the English mill company.

The English mill was erected in 1900 by Mr. P. A. English, and in Feb., 1902, was incorporated with the United States Gypsum Co.

Mr. Powers, in 1896, put down a shaft within the city on the bank of the river near the west end of the G. R. & I. R. R. bridge, and struck the 12 foot gypsum stratum about 60 feet below the bed of the river.

ALABASTINE MILL AT GRAND RAPIDS.

The rock is hoisted through an 85 foot shaft to the floor of the mill on the bank above.

§ 4. History of the Grandville District.

The town of Grandville is located six miles southwest of Grand Rapids on the Grand river, and at the present time has only one mill in operation. The old proverb that "it is an ill wind that blows nobody good" appears to have found one of its applications in this section, for in the 60's a high wind overturned an old tree, revealing in its roots some small blocks of gypsum, and the ledge was soon exposed. In 1872, Wm. Cahoon & Co., of Detroit, organized the Union Plaster Co. and built a mill south of Grandville, afterward known from its color as the Red mill. In 1873 Nearpass & Co. built a mill across the road which was painted white and became known as the White mill. In 1874, by foreclosure of a mortgage on the properties, the mills and quarries passed into the possession of the Union Mutual Life Insurance Co., and in 1878 this company operated the mills through Mr. T. N. Brosman as agent. In 1880 Brosman and McKee bought the property and incorporated in 1881 as the Union Mills Plaster Co. with a capital of $150,000. The Red mill was equipped with three runs of 42 inch French buhrs and with nipper and cracker, with a capacity of 120 tons a day, a 150 H. P. engine, and three boilers. There were three eight foot kettles and the conveyors, elevators, etc., for the proper handling of the product. The plaster was cooled in large pans under which water was pumped by a force pump in the engine room, and the warm water was carried back to the boilers. The old quarry of the Red mill had been abandoned before this time on account of the expense of running two quarries, and the rock for both mills was obtained from the White mill quarry, where the 12 foot ledge is covered by about 8 to 10 feet of gravel and soil. The rock was stored in five long sheds and was sorted for the land plaster and for the calcined plaster. The side tracks of the Chicago and Western Michigan railroad were built in close to the mills affording excellent shipping facilities.

During 1881 they produced 6,077 tons of land plaster and nearly 6,000 tons of calcined plaster. A few years later the property was sold to Frank Noble and was again sold about 1896 to Mr. Dummer of Chicago, who still owns the property, though the Red mill has been dismantled and abandoned, and the White mill has not been running for the past four years.

A short distance north of the White mill quarry is the quarry of the Durr mill. This mill, located three-quarters of a mile to the west, was the Weston flour mill, to which an addition was built for the manufacture of plaster in 1875, and it became the property of Lafayette Taylor and Loren Day, who operated it under the name of the Wyoming

Plaster Mills Co. Soon after this time it was bought by Mr. Day and then sold to Mr. Durr in 1886-7. The mill has been burned three times, the last fire being in 1893. The mill and quarry were sold in 1902 to the United States Gypsum Co., the present owners.

In 1875 Mr. M. B. Church secured his patent for Alabastine wall finish, and a company was organized in 1879 and built a mill near the Wyoming mill. The plaster was secured from the Union Mills Co., and the preparation of the mixtures made in the Alabastine mill. In 1883 Mr. Church and the Seeley Brothers built a new mill near Grand Rapids on the present location of the Alabastine mill.

§ 5. History of the Alabaster Deposit.

Bela Hubbard, describes[1] a geological expedition in 1837 to this region in company with Dr. Houghton, and in his notes mentions the discovery of gypsum at the mouth of the Au Gres river.

"In the interests of the scientific object of our tour, I will here observe that near the Au Gres river we discovered, beneath the clear water of the bay, a bed of gypsum. Subsequently an outcrop of this mineral was found on the neighboring land, and has long been quarried with profit."

The plaster beds near Alabaster were first discovered by early Indian traders who noticed the outcrop in the waters of the Saginaw Bay. In 1841, on the completion of the first government survey of this district, Mr. Wm. McDonald, an Indian trader in the employ of the American Fur Co., made an entry a mile in extent along the shore. He later sold a portion of his interest to James Fraser, Harvey Williams and Alfred Hartshorn, who explored the beach but found nothing except gravel and sand. Others later sought for the gypsum in the sink holes of the region, for they failed to recognize the fact that these places owed their formation to the loss of gypsum through solution.

In the later 50's Wm. S. Patrick carried the mail through this section from Alpena to Bay City by dog train. An old squatter, who had taken possession of some land near the present Alabaster quarry, one day showed a piece of the gypsum rock to Patrick, who took it to Bay City and showed it to Mr. Geo. B. Smith. Mr. Smith's father, B. F. Smith, owned a quarry near Sandusky and a gypsum mill in the city of Detroit. Patrick, on his return, bought the land, paying for it two dogs and $10, and he in turn sold it to Mr. Smith, who opened the first quarry in 1862. On the death of Mr. Smith, Mr. A. F. Bullard, B. F. Bullard, and the estate of G. B. Smith formed the company of Smith, Bullard & Co, and in 1876 the name was changed to Smith and Bullard, who sold to B. F. Smith, who in turn sold a part interest to W. A.

1 A Michigan Geological Expedition, a paper read before the Historical Society of Detroit and published in Michigan Pioneer and Historical Collections, Vol. III. p. 199. Memorials of a Half Century, p. 86.

Avery and T. G. McCausland, operating under the name of B. F. Smith & Co. This company was reorganized in 1891 as the Western Plaster Works and changed to the Alabaster Co. in 1898. It is now known as the Alabaster plant of the United States Gypsum Co. In 1891 fire destroyed all the property and the mill was rebuilt in 1892, and another mill was built at South Chicago to supply the World's Fair trade.

In the early days of the Alabaster quarry development, small mills for the manufacture of land plaster at Winona, West Bay City, and Monroe were supplied with the Alabaster rock.

The first apparatus used for calcining was a system of revolving cylinders which proved unsatisfactory, and these were soon replaced by kettles. The fuel used for the purpose of calcining was wood until 1898, when the railroad switch was built and coal replaced the wood.

In 1870 Mr. Chas. Whittemore, a lumberman of Tawas City, opened a second gypsum quarry about three miles south of the Alabaster quarry near the water of the bay, and made land plaster for the farmers of that region, but on account of trouble with water abandoned the work a year or so afterward.

At the present time the Alabaster Co. has established a hotel, post-office, and some 40 dwelling houses for the workmen, forming a very comfortable town located six miles from Tawas City and 42 miles from the mouth of Saginaw river, fronting the Saginaw Bay. They own about 200 acres of land and have built a two story warehouse and 600 foot pier for loading the sailing vessels, and the town is connected by switch with the Detroit and Mackinac railroad, which connects with the Pere Marquette at Bay City.

CHAPTER IV.

GEOLOGY AND TOPOGRAPHY OF GYPSUM OF THE MICHIGAN SERIES.

§ 1. Geological Section.

The geological formations of the Lower Peninsula of Michigan are represented by an interior Coal Measure basin (Fig. 8), surrounded by

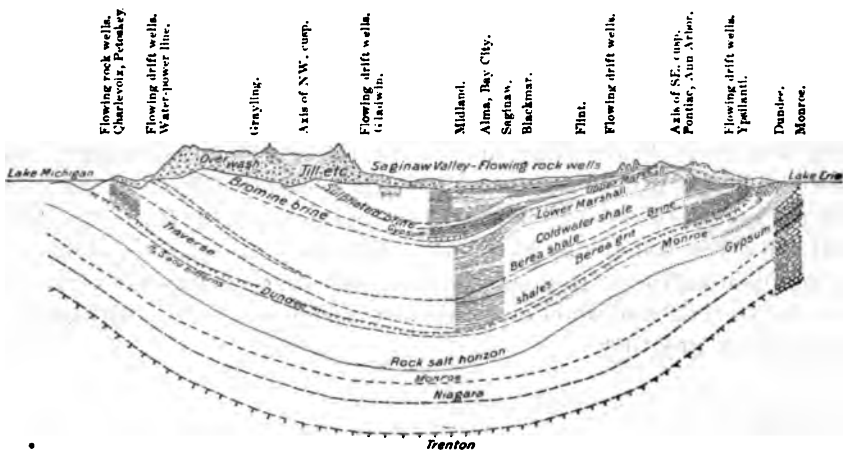

FIG. 8. Cross section of the Lower Michigan Basin. Horizontal scale, 1 mile = .135 inch; vertical scale, 1,200 feet = .321 inch.

From U. S. Geol. Survey Water Supply Paper No. 30.

more or less complete and irregular concentric circles of the older formations down to the Lower Helderberg, or Monroe dolomite, the uppermost stratum of the Silurian.

The division which is of special importance in the study of the gypsum deposits is the Sub-Carboniferous of the older geologists. The lower portion of this formation had been named before 1870 the Waverly by the Ohio geologists, and in Michigan had been called by Winchell the Marshall. In this same year he proposed the name Mississippian for all the rocks from the Burlington limestone up to the Chester limestone in the Mississippi valley.

In 1891 Prof. H. S. Williams proposed to substitute for Sub-Carboniferous, the name Mississippian series "to include all the formations con-

taining Carboniferous faunas from the top of the Devonian to the base of the Coal Measures." He further divided the series into three epochs; from below upward, Chouteau, Osage, and Ste. Genevieve. Keyes later divided the series into four epochs, the Kinderhook = Chouteau, the Augusta = Osage, the St. Louis and Kaskaskia = Ste. Genevieve.

The Chouteau was named from the Chouteau limestone of the Mississippi valley. This stone was later found to be equivalent in age to the Kinderhook of Illinois, a name given earlier and so entitled to hold by the law of priority. The Osage formation included the Burlington and Keokuk limestones. Keyes proposed the name Augusta for the group, because of the typical development of the formations near the town of Augusta in southeastern Iowa, and also because the rocks designated as Osage were later shown to be Burlington in age.

Above the Augusta or Osage is found the St. Louis limestone, overlain in part of the area by the Chester shales. These shales were first named in print in 1865, but Hall had given the name Kaskaskia to the same group in 1856. Some writers have united these two groups under the name of St. Louis-Chester, or Kaskaskia, but according to Keyes, the Kaskaskia and St. Louis "were separated more widely than any other two members of the entire Carboniferous of the continental interior, faunally and especially stratigraphically."

The Waverly group of rocks in Ohio appears to be equivalent in part to the Marshall of Michigan, the Kinderhook of Illinois, and to the Chouteau of the Mississippi valley. This correlation was made many years ago, and through error was regarded as equivalent to the Chemung division of the Devonian of New York.

In Michigan, Winchell,[1] in 1862, described a series of sandstones, 296 feet in thickness, whose upper portion was more firmly cemented and more homogeneous than the lower, and further contained fewer fossil remains, in fact was almost without organic remains. The upper part was called the Napoleon Group, or the Upper Marshall, and the lower portion was called the Marshall Group, equivalent to the Waverly in Ohio.

Above this series, in the vicinity of Grand Rapids, is a group of shales, limestone, and gypsum layers, called by Winchell the Michigan Salt Group. This formation has been shown by Rominger and Lane to be destitute of salt beds, and the Saginaw valley and principal Michigan brines come from below this horizon, so that it seems advisable to follow Lane[2] and call it merely the Michigan Group.

Above the Michigan Group comes the Carboniferous limestone of Winchell, exposed at Grand Rapids and other places around the border of the coal measure basin. It is equivalent to the Bayport limestone

[1] Amer. Jour. of Science, Vol 33, pp. 352-766; 1862. Bull. U. S. Geol. Survey, No. 80, p. 177, by Williams

[2] Mich. Geol. Survey, Vol. VII, Part II, p. 13.

of eastern Michigan, to the Maxville limestone of Perry and Muskingum counties in Ohio, and to the upper part of the St. Louis limestone of the Mississippi valley. Over the Carboniferous limestone, the Saginaw Coal Measures are found forming the interior basin. The Waverly group of Michigan, including the rocks described up to the Carboniferous limestone, according to Rominger,[1] "forms underneath the drift, the surface rock over half the extent of the Peninsula, but its natural outcrops are very limited, either horizontally or vertically."

The Mississippian series in Michigan forms a basin shaped fold, and in the center of the Peninsula it is overlain by the Coal Measures, and can only be mapped in such sections by the aid of well records.

The whole series of Michigan presents more or less irregularity, in places represented by shales, and again by sandstone apparently contemporaneous. The Michigan group in places is cut out entirely on the border of the Coal Measures, and again the Bayport limestone is present and the lower gypsum beds are gone. This limestone at Grand Rapids is about 50 feet thick and rests on the gypsum formation.

In the interpretation of the geological history revealed by these rocks and their relations, the writer wishes to acknowledge his indebtedness to the various papers of Weller, Lane, and Keyes.

§ 2. Geological History of the Michigan Basin.

At the opening of the Carboniferous period, Lower Michigan, Ohio, and a large part of Pennsylvania, were covered by a gulf which opened to the northwest across Illinois and Minnesota. In the earlier part of the Mississippian epoch, the land was sinking around this gulf, especially to the south and southwest, and in this sinking area were deposited the sediments of the Kinderhook stage, forming limestones, sandstones, and shales, mainly shallow water deposits irregular in extent, varying in fossil contents, so that the same series of rocks has been given a variety of names by geologists. These names are often used in local geology, but now are known to be contemporaneous, and they are included under the name of Kinderhook.

By the close of this division of time, the large gulf extended south into Arkansas and Tennessee and west to the Rocky Mountains, and opened northwest across the Dakotas.

For a long period of time the salt water gulf remained stable and quiet supporting a rich fauna of corals and crinoids which have formed the Burlington and Keokuk limestones known throughout the world on account of the variety and perfection of their crinoid and brachiopod fossils. These limestones and other formations, related in time, have now been grouped under the name of Osage or Augusta.

[1]Mich. Geol. Survey, Vol. III, Part I, p. 69.

The following sketch (Fig. 9) by Lane.[1] modified from Keyes' section, will show the relations of the rocks of the Mississippi valley to those of Michigan.

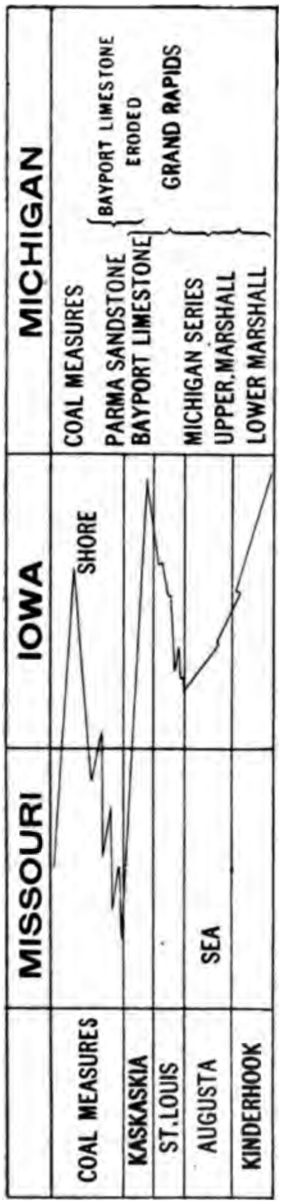

FIG. 9. Diagram showing the relation of the rocks of the Mississippi Valley to those of Michigan, and the advance and retreat of the shore line in the early carboniferous time.

While there were many local and minor variations in the physical conditions, and therefore in the life characters in this gulf, there was a greater and more important contrast in these characters between the eastern and western portions, separated by the Cincinnati island. These have been named by Weller[2] the eastern or Waverly province, and the western or Osage province.

In the Kinderhook gulf, the faunas were intermingled to a very considerable extent; but in the Osage age, the clear waters of the Osage gulf supported a fauna which could not flourish in the sediment laden waters of the Waverly province.

The land to the northeast of this Carboniferous gulf was above sea level, the drainage system of that highland carried a large quantity of mud and sand sediment into the Waverly gulf, forming the conglomerates, sandstones, and shales of that area. The Cincinnati island afforded a partial barrier to the drifting of the sediment into the clearer Osage waters beyond.

At the close of the calm Osage age came a series of uplifts and depressions, whose effects are seen in the Mississippi valley and at the east. The St. Louis limestone was formed in waters extending 200 miles further north than those of the Osage, and this northward extension was followed by a retreat of 400 miles to the south.

In the eastern part of the Waverly gulf, the changes began earlier

[1] Mich. Geol. Survey, Vol. VII, Part II, p. 15, and Vol. VIII, Fig. 2.
[2] Journal of Geology, Vol. VI, p 308.

than in the Osage gulf, and the coast line, according to Lane,[1] receded westward from western New York and central Pennsylvania, until a large part of Ohio and Indiana were out of water by the end of the Marshall or Waverly age. This left the Michigan basin enclosed between the mass of land at the northeast, and probably also at the northwest, and the low land over northern Ohio and southern Michigan.[2]

On the south side of this low land were deposited the sediments forming the coarse sandstones and conglomerates of the Logan group laid down irregularly in Ohio with an average thickness of 200 feet. To the north side were deposited the sediments forming the rocks of the Michigan group, shales, limestones, and beds of gypsum.

The Mississippi extension of the St. Louis is represented in Michigan by the Bayport limestone, in Ohio by the Maxville, which comes above the Michigan Group. This group would correspond in time with the Burlington and Keokuk, or the Osage (Augusta) of the Mississippi valley. The thickness of the group in Michigan is 232 feet (Lane, Vol. VII, Part II, p. 16). the Augusta in Iowa is 230 feet, the Logan in Ohio 200 feet.

§ 3. Michigan Group.

The Carboniferous, Bayport, or St. Louis, limestone in Michigan is also called by Lane the Upper Grand Rapids series, and the Michigan group is known as the Lower Grand Rapids.

At Grand Rapids, the typical locality for the section, the lower series outcrops to the south of the city as a group of shales, thin bedded limestones, and gypsum layers; while the upper series outcrops along the river in the city nearly to its north limits.[3] A number of quarries have been opened in the bed of the river, and, according to Rominger, the contact could be seen at the foot of the Rapids in the earlier history of the city. This limestone is about 50 feet thick, and the continuation of the section downward is given in the chapter on well records.

The only localities in Michigan where gypsum is found in this formation near the surface, are in the vicinity of Grand Rapids and at the east near Alabaster. The formation, however, is found in a belt of varying width bordering the coal basin, and throughout the most of the area it is more or less concealed by the overlying drift.

§ 4. Glacial Geology of the Grand Rapids Area.

Mr. Frank Leverett has made careful studies on the glacial geology of the area around Grand Rapids, and a condensed account of this geology was prepared by Mr. Leverett and published in a report on the Grand Rapids flora, by Miss Emma Cole.[4] Mr. Leverett has kindly sent me a copy of this part of the report, which is as follows:

[1] Michigan Geological Survey, Vol. VII, Part II, p. 15.
[2] The extension of the Cincinnati island above mentioned.
[3] See Whittemore Proc. Mich. Acad. of Sciences. Also Strong. Proc. Kent Sci. Inst. No. 3.
[4] See also paper by B. E. Livingston, in Ann. Report for 1901.

ALABASTER GYPSUM QUARRY SHOWING BOULDER CLAY.

"The features are somewhat intricate, but they fall in naturally with the view that there was a conjunction of two lobes in this vicinity. When the ice extended nearly to the southern border of Michigan, the junction between the Saginaw and Lake Michigan lobes was in a great belt of gravel that is traversed by the Grand Rapids & Indiana R. R. south from Kalamazoo, and the point of the reentrant angle was in the great ridges southeast of Gun Lake.

"From this position the ice melted back until the point of the reentrant angle between the ice lobes was at the Dias Hills, a few miles south of Grand Rapids, and there a halt of some length occurred. The gravel tract between Dias Hills and Gun Lake was formed at that time.

"The ice then melted back sufficiently to bring the reentrant angle up to the bend of Grand River at Plainfield, and again halted. At that time the Lake Michigan lobe formed the ridges and hills that lie on the west side of the Grand River from Rockford to Jenison, and its margin continued southward past Jamestown. The Saginaw lobe at the same time covered the region immediately east of Grand Rapids, its margin being in the eastern edge of the city; and it built up the rolling country around Reed's Lake, and its continuation in the districts to the north and south. Meantime the water found its escape southward over the site of Grand Rapids, and on through the gravelly lowlands that lead past Carlisle to the Black Ash Swamp, and thence to the pine plains of western Allegan County, where it entered Lake Chicago, a lake that then filled the south end of the Lake Michigan Basin and discharged southwest past Chicago to the Illinois and Mississippi rivers.

"In melting back from this position, the ice next made a stand near Cedar Springs, and built up the prominent ridges northeast of that village. From these ridges the margin of the Saginaw lobe passed east of south near Nagle Lake to Grand River below Lowell, and thence on past Alto, while the margin of the Lake Michigan lobe passed southwest near Sparta and Englishville and formed the western part of the great belt of rolling land west of Grand Rapids.

"At length, after several halts that need not be enumerated here, the Saginaw lobe had melted so far back that its front was on the slope towards Saginaw Bay. A lake then formed in front of it, known as Lake Saginaw, which discharged down Maple river to Grand River at Lyons, and thence on past Grand Rapids into Lake Chicago. The channel divided near Jenison, one branch turning down the present river to enter Lake Chicago near Lamont, while the other led southwest past Hudsonville to enter the lake at Zeeland. Great gravelly deltas were formed by each branch of the old outlet at the places where they entered the lake. Much of Allendale Township, Ottawa County, is in the delta of the north branch, while Zeeland stands on the delta of the south branch. As these gravelly deposits are now 60 to 70 feet above Lake

Michigan, it is certain that the level of Lake Chicago was about that height above the present lake. Later it dropped to lower levels, and the outlet of Lake Saginaw along Grand River valley become correspondingly deepened.

"The variations in the drift material gave rise to several classes of soil ranging from heavy clay through loamy clay, clayey loam, sand and gravel, up to coarse cobble. It is usual, however, to find in gravelly places a sufficient amount of fine earthy material to afford a suitable matrix for plant roots.

"Perhaps the coarsest deposit within the Grand Rapids district is that in the old lake outlet. Between the city and Grandville the current of water removed the fine material to such a degree that the soil is very stony. In the western part of Grand Rapids and for some miles above the city large numbers of boulders were present in this outlet before the residents made use of them in building. The soil among the boulders was, however, not too coarse for plants to thrive. This same lake outlet carries also some of the most extensive swampy tracts in the district; the Zeeland swamp southwest of Hudsonville, the Cedar swamp west of Jenison, and the Burton Avenue swamp southwest of south Grand Rapids, being illustrations. But this swampy condition is due to subsequent plant growth in the part of the channel having exceptionally flat bottoms, rather than to any deposit made by the outlet. It is found that sand and gravel deposited by the lake outlet underlie all the swamps at a depth of only a few feet.

"The strip of gravelly sand which extends from the bend of Grand River near Plainfield southward along the east side of Grand River through Grand Rapids and to Carlisle, being in the line of a stream of water, carries but a small amount of clayey or fine material, and is less productive than the heavier soils on the borders of this old stream course. In the immediate vicinity of Grand Rapids it has the further disadvantage of being situated on the border of a deep valley into which the waters drain rapidly after a rain. The lightness of the soil is shown in the character of the vegetation, it being a strip of 'oak openings.' In this old stream course, the extensive Black Ash Swamp has been developed; but, as in the lake outlet, this is due to subsequent plant growth, and sand may be found by probing to the depth of a few feet.

"The grade of soil next finer than the gravelly sand of the old stream courses is the sand found on the bluffs of the Grand and Thornapple rivers above the bend at Plainfield and on the border of several tributaries of Grand River, both above and below Grand Rapids. These sandy deposits have apparently in some cases been drifted beyond the limits of the streams that contributed them, being very irregular and patchy.

"The greater part of the Grand Rapids district lies on the uplands that were feebly or imperfectly acted upon by currents of water during the melting of the ice sheet.

"As a consequence, the soils contain a large amount of fine material together with the coarse stones of the drift. The proportion of fine material determines whether it is a heavy clay, a porous clay, or a loamy soil, and this proportion often varies greatly within the limits of a small field. In these uplands there are numerous basins formed by the irregular heaping of the drift, aided perhaps by the unequal settling of the drift material. These, because of imperfect drainage, usually contain either lakes or swamps. The basins are especially numerous in Grand Rapids Township, from Reed's Lake northward, but are not rare in any part of the uplands of this district."

§ 5. Topography of the Grand Rapids Area.[1]

The Grand Rapids area in Kent county is drained by the Grand river which rises in the southern part of the State in Jackson Co., and flows northwest past Lansing, turning west near Ionia, making a horseshoe bend to the north near Grand Rapids and. flowing south through that city, turns southeast to Grandville, where it takes its northwest course again, emptying into Lake Michigan at Grand Haven. Its length is over 275 miles, including windings.

The Grand river flows from the north through Grand Rapids in a series of rapids which terminate below the center of the city near the Fulton street bridge. The river falls less than one-half foot in a distance of one mile from north of the city limits to Coldbrook street and in the next mile the fall is 12 feet, and from the lower part of the city to Lake Michigan, a distance of 50 miles, the fall is only 5.8 feet.

The river flows in a very straight channel, 600 to 900 feet in width cut in the valley, which is one mile to one and one-fourth miles wide. The banks on either side of the valley form bluffs 150 feet in height. Near the city the river is close to the east bluffs, but towards Grandville the valley broadens to the south.

The bluffs are gravel ridges cut by erosion into elongated or rounded hills. One of these extends through the city, east of the river, from Coldbrook avenue near the north end of the city, to Fulton street, a distance of one and one-fourth miles. A second ridge, really a continuation of the first one, extends from south of Fulton street to the south end of the city. The ridges are composed of gravel and boulders of varying size, with occasional boulders of limestone and gypsum. The river plain is composed of sand and silt.

To the south of the city the drainage is carried into the river by Plaster Creek, which rises in the southern part of Kent county and flows

[1]See map published in Annual Report for 1901.

north for eight miles and then northwest for about ten miles. Near Grandville the area to the south is drained by Buck Creek. which rises in the vicinity of the head waters of Plaster Creek and flows northwest ten miles. These two streams are small, but they formerly furnished water power for the gypsum and flour mills near their mouths.

The towns in the gypsum area are Grand Rapids, a city of 100,000 people, with its numerous mills and furniture factories; and Grandville, a town of a few hundred people. The area is traversed by the Pere Marquette R. R., which passes through Grand Rapids and through Grandville to Holland and Chicago. The Grand Rapids mills are also reached by the Grand Rapids and Indiana, and the Lake Shore and Michigan Southern railroads. The Detroit & Milwaukee branch of the Grand Trunk system also crosses the area.

§ 6. The Alabaster Area, by W. M. Gregory.

1. The Size of Area.

The area under consideration (Plate IV) is located on Saginaw Bay on the northeastern side of the Lower Peninsula of Michigan, comprising parts of the counties of Arenac, Ogemaw, and Iosco. The size of the area is some 40 by 30 miles, and comprises some 600 square miles. The geological formations here exposed extend from the Coal Measures to the Coldwater shales. The former State geologists Rominger and Winchell accomplished the most work, which was confined principally to the outcrops along the Lake Huron shore. Some of the outcrops of the interior which have not been described before will here be treated.

2. General Topography. Highest and Lowest Land.

The highest land of this area is in the northwest, the contour map showing a general slope from the northwest to the bay. The greatest elevation (850 A. T.) is at Turner's Corners, southwest of Maple Ridge, and other points which have considerable elevation, are Maple Ridge, which is on the crest of the Saginaw moraine and has an elevation of 803 A. T., and Pinnacle Hill, which is the highest point south of the Rifle river, and has an elevation of 765 A. T.

The lowlands are found bordering the lake shore and extending up the river valleys. Some of these lands include large marshy "prairies," such as are found at the mouth of Rifle river and along the lake shore near Pine river and Saganing.

3. Glacial Geology.

The surface forms of the region are due to glacial action, in fact the predominating character of the surface topography outside of the lake formations was determined by the great ice sheets, which recently, in a geological sense, covered this country. These forces were not always destructive, but frequently constructive. The old rock surfaces which

existed before the time of the ice cap have been smoothed off and the old valleys filled with glacial till. Distinct traces of some of these old valleys are found some four miles west of Alabaster, running north and south. Here wells are often drilled through the drift some 150 feet before reaching the rock.

Where the end of the ice sheet stood for a long time large mounds of assorted till were made on top of the rock. These mounds were continuous along the ends of the glacier and now stand up as high ridges or moraines. The crests of some of these moraines are seen in the region of Sterling, Prescott, and Taft. The drift is nowhere over 150 feet in thickness, its average depth is from 25 to 40 feet.

The moraines which are now present are moraines of retreat, the earlier ones being scrubbed out by advance of ice; the height of these moraines is never over 100 feet above the general surface of the country and some of them may be traced continuously across the country. One of the most prominent of the moraines of this region starts in the southwest near Moore's Junction and passes across to Sterling, Summit, Prescott, and Taft, and has been called by Taylor, the Port Huron-Saginaw moraine. This is the highest moraine on the map, Plate IV, and marks the position of the Huron ice lobe during one of the periods of retreating glaciation.

The one which starts at Harrisville and Alcona is traced southward to a point north of Tawas Lake down to the Vines P. O. and, curving slightly to the southeast, to a large spur midway between Tawas City and Alabaster, where it drops off sharply, may be traced as a water laid moraine from this place to Au Gres, where it passes into Lake Huron. The Alcona moraine in the region of Alcona is very marked in its morainic character, being very rolling and irregular in outline; as it is traced to the south it becomes more subdued, exhibiting its water laid character. The bedding at Seven Mile Hill on the Au Sable and Northwestern R. R. shows clearly that the ice once stood at the eastern edge and that the drainage was to the west, forming the Au Sable overwash plains which are traced as far south as Moore's Junction, always being found as sand beds just west of this clay ridge. This moraine is believed to exhibit one of the characters which is peculiar to moraines passing from surface forms to water laid forms. It was formed after the Saginaw-Port Huron moraine and a string of lakes exist between the halt of the two moraines.

The interesting feature which always accompanies the moraines in this region is the overwash plains, or as they are more popularly called the sand plains. These are very familiar to the residents of the district as being regions which absorb water very rapidly and contain no soil which is adapted to cultivation, and grow a familiar plant society characterized by jack pine, sweet fern, and scrub oak. As has been before

stated, these plains were formed when the ice stood on the different moraines and are the products of drainage along the western edge of the ice. In some places, such as Iosco county, north of Tawas City, there is quite a deep trench between the place where the ice stood and the plain; this is believed to be an excellent example of "fosse." The sand plains in the region of Pinnacle Hill were formed as a delta in some stage of the glacial Lake Warren, those in the region of Alger being formed in an earlier stage of the lake called Saginaw by Taylor. These sand plains comprise all the northwestern parts of Iosco county and almost wholly the entire northwestern section of Arenac county.

The conditions which were present during the retreat of the glaciers were such that at the south and west was higher land, and the ice as it stood on the moraines often extended across to higher land in the south, so that in front of the lobes was a lower region than that of the surrounding surface, which filled with water from the melting and retreating glacier, and thus glacial lakes were formed. The beds and beaches of these old lakes form a very conspicuous feature of the topography of this area. That these lakes persisted for a long time is clearly certain from the extent of their beach lines and their development and many lake histories have been recorded and perserved by these fossil beaches. The highest beach of this region is that of old Lake Saginaw. It was into this lake that the early drainage of the Au Sable river was directed by the western edge of the ice. The next lake which left two distinct beaches was Lake Warren. The first beach was the Upper Forest,[1] usually formed at 775 A. T. This beach is very distinctly shown in the region of Sterling, and is found again as a beach of water worn gravels east of Maple Ridge, is present north and east of Whittemore, and is believed to be bordering on Bissonette, Tp. 24 N., R. 7 E., Sec. 11. The lower one is well developed, and marks a slight fall in the level of Lake Warren, and is traced from Sterling across to Emery Junction and the edge of the sand plains northward to Seven Mile Hill. It is believed that while the lake stood at this level and at the place preceding, that the delta which comprises the region of Pinnacle Hill in Arenac county, was formed. The Grassmere[1] beach is not distinct in the northwest but seems to appear in the vicinity of Deep river on the Michigan Central R. R., having an elevation of 655 feet A. T. It is made out rather indistinctly at the edge of the old or Pinnacle Hill delta, and it appears again west of Turner, in a well marked ridge, and it is traced to the northeast to a point south of Emery Junction, where it extends directly east on top of the well marked lobe of the Alcona moraine, and nearly reaches Lake Huron, having an elevation of 650 A. T. Thence turning north,

[1] The correlation of these beaches is with the Huron county report, Vol. VIII. At the date of publication Messrs Leverett and Taylor are engaged in revising this, and changes may be involved in the names. L.

going west of Tawas City and also of Tawas Lake, it is believed to pass along the foot of Seven Mile Hill. The Algonquin Beach is the best marked of all these beaches and has been traced almost continuously across this region. It is first found in the southeastern part of Arenac county, west of the D. & M. R. R., having an elevation of 605 A. T., and being well developed in this region. This is traced easily to Pine river in a series of beaches, which are some 15 to 20 feet above the level of Lake Huron and have in front of them smooth till plains. This is something exceptional in the way of beach structure and may be explained on the supposition of the formation of these beach ridges by means of push ice in old Lake Algonquin. On going north the beach becomes indistinct in the region of Au Gres swamp, but is found appearing again clearly at Alabaster, with an elevation of 605 feet A. T. It is traced along the front of the Alcona moraine a way, and then disappears, being cut away, until it reaches Tawas City, where the beach is found and a well developed bar which formed in front of the beach and eventually became the beach by the cutting off of the water in the rear. This little episode in the history of the Algonquin beach and the formation of the lake back of Tawas City and the subsequent drainage of this lake is very clearly shown in the region called the "glen." The next beach below the Algonquin is the Nipissing and is in places, in the southern part of Arenac county, not over 10 feet above the level of Lake Huron. Its chief features are destroyed in many places by erosion, or wind action accentuates its normal development. In the upper part of Iosco county the beach is 15 to 20 feet above lake level and is, if exposed to the wind, sure to be changed into ridges which are slowly traveling the shore. Such dunes are shown at the old Hale mill and also at the Tawas Beach Park resort. Some of these dunes show what might be termed wind ripple action, being blown into little ridges, which are exactly similar to ripple marks formed in shallow water. A few of these dunes travel quite rapidly, and in some of these places trees have been known to survive passage of sand over them.

4. Additional Relief Forms.

Most of the forms which are a conspicuous part of the topography are due entirely to glacial action, and as erosion has had but a small opportunity to work over these forms, the prevailing relief is one of youth—maturity in land form development being reached only along the river bottoms and lake shores, but erosive action has been enough in some places to accomplish a considerable cutting away of the old lake beaches. The inland lakes are as yet but little filled and the swamps are largely the result of the immaturity of the drainage system. The Au Gres swamp is an excellent type of this development.

One of the features of the old rock topography, the only remnant of this form which has an influence on the present surface features, is the limestone ridge which extends from Point Au Gres west to Duck Lake, from thence north and west to the Griffin quarry and the Tyler outcrop, becoming lost underneath the drift of the northwest. This ridge stands up because of the hardness and the lithological character of its composing members, which are a hard dolomitic limestone and hard calcareous sandstone.

5. Recent Shore Forms.

Between the lake level and the Nippissing beach is a strip of land which is due entirely to recent lake formations and some of these are within recent historic times. The general shore structures of the eastern edge of this area show the direction of the adjustment of the beach to the lake currents by the smooth curves convex to the present in the outline of the shore, both in the larger features and the smaller ones (?). The most interesting place where these recent formations have been more rapidly built, is at Tawas Point. The places in the "bight" of Tawas Bay show how the building at this point is gradually weakening the building effects of the waves on the shore.

One of the familiar features along shore is that of sand dunes; in many places arranged by storm waves and wind action into lenticular dunes with the longer axes northeast and southwest. These are often cut into several smaller ones, later by wind action or perhaps the entire top blown off, forming a dune which resembles a crater of an old volcano.

The Tawas river and other rivers of this section have a tendency to build deltas where the force of the river currents is less than that of the lake currents. This has taken place at the mouth of Tawas river. The building takes place in the summer and in the spring and fall. The current of the Au Sable is much stronger than the prevailing lake currents and the sediments are carried some two miles down the shore, where, according to Capt. Small of the Tawas U. S. Life Saving Station, there is a large shallow area, some one-half mile off shore, and this is being converted into an island. The Rifle river has built a large delta at its mouth, some five miles square in area, and the Au Gres river has a current which is so sluggish that a channel to the Saginaw Bay is kept open with difficulty, and a long area of land in front of the river mouth is slowly forming into the river delta.

6. Sink Holes.

Some of the forms which are very limited in extent, but constitute a peculiar feature of the surface, are known as sink holes, and have been formed in the limestone or in the gypsum by the dissolving action of the water forming large circular pits, 10 to 15 feet across and 9 to

ALABASTER GYPSUM QUARRY SHOWING GYPSUM LEDGE.

10 feet deep. Such structures are found below Alabaster in Iosco county, also west of the D. & M. R. R. near the Dryer place, and at Glendon dam on the east side of the river; these structures, while not an important topographic form, are believed to be important in the drainage of the region in which they are found and are the best developed at Alabaster of any of the regions in which the structures occur.

7. *The Drainage.*

The drainage of this region is largely determined by the character of the country, as the rain fall of the sand plains passes quickly to the water table, which is on the underlying clay whose depths from the surface averages near 15 feet, while the water falling on the clay flats is almost all held on the clay surface until removed by the surface drainage. The sand plains give rise to a large number of springs at their edges or in the regions where they are cut by the rivers. All the creeks of this region which are important feeders of the larger rivers can be traced directly to their origin on the edge of the sand plains. The springs at Pinnacle Hill on Rifle River are an example of springs formed by a river cutting down to the under clay of the said plain, and there are several such springs found along the Au Sable river. Along the Au Gres river are many of these springs, which appear between the sand and the under clay. The entire drainage of the eastern half of this area is very irregular and discordant. The shortest and most natural route for the water to take to the lake, is effectively blocked by the Alcona moraine, and the water falling quite near to the lake is carried away some distance to the Au Gres river, where it slowly passes through the Au Gres swamps and out to the lake. In the spring swampy lands along the Au Gres slowly fill with water, which renders useless for a long period during the early spring a large tract of land which would otherwise be excellent for cultivation. Attempts have been made to remedy this by clearing out the outlet of Duck Lake and by building drains to carry the water directly into the Au Gres river, as the drain east of Twining and also the "Bum" drain east of Turner. This condition in the region of Alabaster is possibly to be corrected by a pretty example of stream capture, as there are many small stream creeks "gnawing" back from Lake Huron into the lake side of this moraine, and in the spring when the water is high in the Au Gres basin, a small part of it comes over the divide in these creeks. One of the largest of these spring creeks is situated midway between Tawas City and Alabaster, and has cut a deep ravine into the moraine here and in front has built a fine alluvial fan or "freshet" delta.

8. *Rifle River.*

The Rifle river is a good example of the typical streams of this section, it having had in former glacial time an abundant supply of

water which brought a large amount of gravel. The river had to aggrade its course because of increased supply of material and as the volume of water became deficient by the retreating of the glacier, the slope of the old river was not steep enough and thus the stream was compelled to grade its course, cutting deep into the deposits of sand and clay gravel. The lowest beds of the formations exposed in the river banks are solid lake deposited clays, which were formed when the lake stood at a higher level and the river had its entrance to the early glacial lakes farther to the north, and then as the shore of the lake was lowered, on top of the clay was deposited a series of overwash deposits, which vary from 15 to 20 feet in thickness and are almost wholly composed of fine white sand. It may be explained that the absence of a deposit of coarse gravels on top of the clay may mean that the lake fell rapidly, giving no time for the deposition by continued action of other shore deposits, than fine sand, not giving an opportunity for the working out of the heavy boulders and pebbles. The river shows, in many places, a succession of terraces cut in the old gravels and in places there are cusps on the spurs. Where the river flows across the moraines the boulders are sorted out and left in the river bed, forming riffles or slight rapids.

The flood plain of this river is not well developed above Omer, but well enough developed so that it sweeps around the ends of some of the spurs and possibly may be classed as a "scroll pattern flood plain." Below Omer the river has many ox-bow cut-offs and a great extension of the flood plains. It has no branches of any size from the south and is fed by spring creeks from a clay country from the north and rises in the region of Rose City and Lupton. At the West Branch bridge, it cuts through an exposure of some 20 feet of Marshall sandstone; below this exposure some two miles there is a formation of limestone and sandy shale which belongs to the Maxville rocks. At a lumber dam, northwest of Pinnacle Hill, there is an exposure of bed rock which may be classed with the Michigan group. Following down some two miles are excellent exposures of fire clay and black shale, exposing a pocket of the coal series of Michigan. The outcrop at Omer is the fine white sandstone which is believed to be the base of the Michigan coal series. This formation is exposed in several other places, from this point down the river to the mouth.

§ 7. The Paleozoic Geological Formations of the Alabaster Area.

In this area are excellent exposures of the Michigan coal series, the Maxville limestone, Michigan series, Upper Marshall or Napoleon and Coldwater or Cuyahoga shales. The outcrops are rare, but all of the formations are represented with the exception of the Coldwater shales. The best outcrops are those of the Maxville limestone and the Michigan

series. Much of the knowledge of the rocks is based upon the records of the salt wells which were drilled years ago to supply brine for salt manufacture, which was carried on in connection with numerous saw mills, which furnished abundant fuel. In only a few towns are the old salt blocks utilized at the present time. Many regions have shallow flowing wells and by a combination of these two sets of well records and an examination of the outcrops, fairly accurate data concerning the surface and depth of glacial drift and the stratigraphy of the old rock have been obtained.

The Coldwater shale is reached by some of these deeper wells on the northeastern border, possibly at East Tawas, and certainly at Au Sable. After considerable careful examination it is still an unsettled question concerning the brine of the East Tawas wells, but it seems quite probable that it comes off the top of the Coldwater shales as when this is reached under cover it is quite salty.

The next formation lying above the Coldwater shales is the Lower Marshall, which is easily recognized by its abundance of red rock, called paint rock by the drillers. This is found in the lower wells at 120 to 800 feet, and in its lower part it alternates with beds of blue shale, with the red rock growing gradually thinner at the bottom of the formation with a corresponding increase in the blue shale beds, and at 700 feet an abundance of brine in a gray sand rock has been found in the East Tawas wells.

At East Tawas the Napoleon or Upper Marshall is represented by some 20 to 40 feet of white sandstone and is the first formation reached. Wherever this formation is drilled into in the county southeast of Tawas an abundant supply of water is yielded, while the lower formation yields a water which is saltier. The flowing wells which are found at Turner, Alabaster, Au Gres, Twining, Omer, Standish, and Pinconning all have wells in this formation. These wells do not pass through any red rock at all, and so it seems that water must come from the Upper Marshall or Napoleon. On Rifle river it has its only outcrop, not a well exposed one, which exists near the West Branch bridge.

The Lower Grand Rapids group or Michigan series is well known to the well drillers because of the prevalence of seams of gypsum alternating with limestone layers and shaly sandstones. The water of the gypsum beds is always very strongly mineralized and unfit for use. The Alabaster quarry, Iosco county, is in this formation, as are the outcrops at Plaster Bluff, Cramer's Creek, Turner, Twining, West Branch and Glendon dam. The gypsum is not uniform in thickness, and in places is interstratified with many stones of hard cherty limestone, and in other regions, as at Turner at the small shaft sunk by Mr. Hand, the seams are brownish dolomitic limestone.

ALABASTER.

The most extensive exposure of the Michigan series is at Alabaster, four miles south of Traverse City, in Iosco county, in the quarry of the North American Plaster Co. A bed of gypsum with an average thickness of 23 feet is covered with a stiff brown boulder clay, free from pebbles, 10 to 12 feet in depth. This one bed,—in reality, two beds, are present as in early working of the quarry a layer of hard fossiliferous limestone and a small layer of shale were between the two beds, which have entirely disappeared in the recent working. The bed has been worked back from its original outcrop on the shore of Lake Huron, nearly a thousand feet, and the face of the bed now exposed is more than a quarter of a mile in length. See Plates VII, VIII and IX.

For convenience in hauling away the rock as it is blasted from the face of the bed, the quarry is being worked in the shape of a huge horseshoe, with the face of the bed on the outside of the bow. The material stripped from the top by steam shovel is carried by tram cars to the center of the bow, making a huge dump which has somewhat interfered with the drainage of the quarry, but offers the least expensive method of disposal of this material.

The top of the bed exposed by the removal of this heavy brown clay is very even, showing a slight dip to the southwest and many small ravines, due to the solvent action of percolatory waters, which generally come through the sandy streaks in the clay.

The gypsum is removed from the surface by blasting, the charges are distributed in steam drilled holes, along the bed, and large masses thrown down to the floor of the quarry, and is here broken by handwork into sizes convenient for the crushers or for shipping by boat.

The dark colored, impure gypsum with a large percentage of clay is utilized for land plaster. A variety which is streaked like castile soap, with irregular seams of clay, is shipped to eastern markets, where it is made into Mexican onyx. The purest gypsum is ground, heated and converted into familiar plaster of Paris. Many of the patent hard finish wall plasters and fancy kalsomines have the calcined gypsum as their chief ingredient. The familiar "stucco" material is the calcined gypsum mixed with size or glue. The larger part of the staff material used for the World's Fair buildings and the Pan-American, came from this quarry.

A 90-foot shaft was sunk several years ago by the North American Plaster Co. to determine the condition of the lower beds of their deposit. The underlying rock of the quarry is a bluish gray sandstone, alternating with seams of hard cherty limestone and brownish sandstone. At different depths several small beds of gypsum occur, the largest one nearly 5 feet thick, and at 85 feet depth. At 90 feet a strong flow of water

occurred, which stopped further work, and it is quite probable that this represents the bottom of the Michigan series.

In the gypsum bed no trace of organic life has been found, but in the early working of the quarry, before the two beds were found blending into one, they were separated by a small layer of shale and limestone from which some fossils were reported by Winchell.

In the report upon the geology of the lower peninsula of Michigan (Geological Survey of Michigan, Vol. III, Pages 105-107) by Dr. Rominger, the bed of gypsum then exposed was only 15 feet in thickness with a few additional feet of shale and flagstones. The recent active quarrying has exposed the present gypsum bed of 23 feet, overlain by 15 feet of drift.

The fossils found by Dr. Rominger were in the middle beds of flagstones and the shells (which have now entirely disappeared) named in the order of their abundance he called: *Myalina, Allorisma, Aviculopecten, Edmondia, Retzia gibbosoa* and *Spirifera speciosa.*

CRANNER'S CREEK.

On Cranner Creek, which is a branch of the Au Gres river in 21 N, R 5 E., in Sec. 20, just west of the junction of this creek with Johnson creek, is a deposit of a very light rose-colored gypsum in its bed, being exposed in a few places for 200 feet along the creek's bottom and the low water of late summer months, showing large holes where the rock has been washed away when exposed to water action. The gypsum is covered by a bluish gray shale with occasional seams of arenaceous limestone. This is a place where some careful exploration of the high clay bluffs might reveal a bed of sufficient quality and quantity for working.

A short distance below the junction of these creeks, at an old abandoned lumber dam, the drift has been moved and shows, at low water, the upper layer brownish limestone of 1 foot in thickness, underlain by a 6-inch bed of pink-tinted gypsum, and some 8 inches of blue shale which rests upon a bed of white gypsum, whose exposure is not enough to determine its character. This seems to indicate that the workable bed of gypsum is below the bed of the creek rather than in the high clay hills which form its valley.

GLENDON DAM.

In Sec. 28, T. 22 N., R. 6 E., 1-8 of a mile above the old Glendon dam on the east bank of the Au Gres river, is a cut which exposes the following sections:—

One foot clay, 4½ feet gypsum, top layers very pink; 3 in. roughly foliated limestone and sandy limestone interstratified; 2 feet of yellow shale; 3 feet of bluish gray arenaceous shale.

This is the only outcrop in this region in which the pink color of the rock is pronounced, and may be due to the fact that this was near an old stream flowing into the basin when the gypsum was being deposited and thus bringing some of the iron salts resulting from decomposition of rock into the water. The color is very uniform and regular, without any indication of being formed by infiltration after gypsum was deposited.

From the sink holes in the vicinity, and the fact that gypsum occurs in the outcrop, a company was organized several years ago and many tests were made by driling, but the results were not satisfactory and failed to show at any place a bed of over 5 feet and the gypsum was pronounced valueless for commercial working and was considered a collection of big boulders rather than an actual outcrop, but the presence of the blue shale in the river bed some distance below and above the outcrop is sufficient to establish this as an outcrop. Careful searching has yielded no fossils.

On the Au Gres river, in Sec. 27, T. 22 N., R. 5 E., the river bottom in the southeast corner of the section is covered with a blue, grayish arenaceous shale, which is so closely associated with the gypsum deposits of this region. Northwest, a quarter of a mile from the southwest corner of this section, a three foot bed of gypsum occurs in bank of the Au Gres river. This is covered by two feet of sandy limestone and underlain by the blackish shales.

Following the Au Gres river through the sections of the southeastern part of the above township, small beds of arenaceous shales are found. A number of sink holes in Sec. 36, outcrops in sections 24 and 12, are reported but have not been found.

At Whittemore, in Sec. 10, T. 21 N., R. 5 E., is a well which penetrated several beds of gypsum at 50 feet and 170 feet. North of Whittemore, at Mr. Armstrong's house, beds of gypsum of 5 and 7 feet thickness were passed at 90 feet and 130 feet in drilling for a flowing well.

WEST OF TWINING.

In the S. W. 1/4 of the S. E. 1/4 of Sec. 23 of T. 20 N., R. 5 E. (Mason) of Arenac county, an attempt has been made to find the thickness and depth of the gypsum bed. This place is due west of Twining 1 1/4 miles, and has an elevation of 648 to 652 A. T. Several small test pits were sunk to the rock, which was found on the average at about 8 feet covering of drift material, largely boulder clay.

One of these pits, on the authority of Mr. Nelson, who assisted in making the tests, has the following strata, a record which, from well records in this vicinity, seems to be fairly accurate:—

8 feet of clay;
3 feet of gray sandstone mixed with small strata of gypsum;
5 feet of gypsum (?), white;
2 feet of gray sandstone mixed with gypsum, rests on 19 (1?) feet pure gypsum. (Very doubtful but not impossible.)

From an examination of the material thrown out of the pits, somewhat different conclusions might be drawn. The amounts of brownish sandstone and gray limestone are about equal. The brown sandstone being found on top with a few streaks of a very hard non-fossiliferous limestone. The gypsum which has been taken out contains much clay and resembles the poorer grade called land plaster at the quarry of the North American Plaster Co. at Alabaster.

The gypsum exists in two forms, one of dark mud-colored lumps which, on breaking open, show inside small irregular masses of pure, white, uncrystallized gypsum, as if after deposition of the material water action had disturbed the water material and brought in much silt which has formed a complete covering for the gypsum. Some iron pyrites were observed in a large number of specimens embedded in the gypsum and running in seams through it. This occurrence of iron pyrites with gypsum has not been observed before in any of the other deposits examined.

A bluish argillaceous shale has been taken out in a large quantity and closely resembles bluish shale from Alabaster and Au Gres river. It is believed that this pit represents the top of the gypsum beds in this region.

At Twining, in drilling the flowing well of William Lilleberger, a vein of gypsum was found at 25 feet, but its thickness has not been carefully observed. In Mr. Barr's well, on Sec. 25, which is south 1½ miles, a 10 foot vein of this same rock was encountered at 20 feet, and the water of several wells in the near vicinity is very bitter, giving with $Ba\ Cl_2$ solution a strong precipitate of $Ba\ SO_4$, which indicates the presence of gypsum in the water. Mr. Barr states that the mineral comes to the surface 40 rods west of his house, but this outcrop has not been found. There is no question but that a bed of gypsum of fair thickness underlies the region of Twining, Turner and Turtle. Its value for working can be deterimned only by careful work with a drill.

KEYSTONE DAM.

The formation which is exposed above the Michigan series is that of the Maxville limestone which usually in this area forms a slight bluff on the southern slope of the outcropping gypsum and in particular in the region of Omer, Au Gres, and if followed to the northwest, on Cranner and Johnson creeks. The relations aid in following the boundaries of these two formations.

The bed of Johnson creek in Keystone dam, in Sec. 30, of 21 N., R. 5 E., is some 8 feet higher than the top of the exposure in Cranner creek, and although some of the intervening beds have not been found, the Keystone dam formation corresponds so slosely in lithological character and in fossils to the beds of Harmon City that its position in regard to the gypsum must be similar.

At the Keystone dam some 800 sq. ft. of rock is exposed. The beds dip only slightly to the S. W. and is traversed by few joints, and the beds are cut nearly 10 feet deep, for a distance of 500 feet by the creek which was formerly dammed at this place. The following description applies to this formation:

2 feet. This is the top layer and is a slight gray, brittle, slightly arenaceous limestone with a conchoidal fracture. Small druses containing crystals of calcite are scattered abundantly through the bed. Fossils, especially *Allorisma,* are quite numerous. Greenish stem-like bodies of irregular shape, occur similar to some of the branching forms of bryozoa. The lower part of this layer is filled with flint nodules in shape and size like those of Harmon City, but are more cherty and of a darker color than those from the Lake Huron locality.

3 feet of dark brittle limestone filled with irregular lime concretions which are found in the Omer quarry. These concretions, when broken open, show excellent specimens of calcite.

1 foot of dark gray arenaceous sandstone or some branching forms of the lower forms, effervescing with weak acid and containing remains of some stems.

4 feet. Beds of gray color, hard and compact and calcareous in upper part, very brittle in the lower part, which is more sandy and with many small seams of fossils and cavities of calcite crystals.

Following the creek down 100 feet from the old abandoned dam, the following section occurs:—

1 foot clay drift;

2 feet limestone, many fossils and nodules. Brittle argillaceous at top and gray arenaceous at bottom.

1 foot brittle cherty limestone with small white streaks of chert.

5 feet gray brittle finely laminated freestone which has a few inches of black shale at its top.

4 feet sandstone of gray color in places, very probably due to weathering. No fossils.

A point 200 feet from the dam another section occurs, which, perhaps, is more of the sandstone of this series and has the following beds:—

3 feet clay drift from the surface.

3 feet gray hard limestone with a few fossils mostly concretions like quarry at Harmon City.

ALABASTER GYPSUM QUARRY DOCK.

6 feet bluish thin bedded sandstone or freestone resembling some of the grindstones with a three inch layer of black shale at top of the bed.
8 feet, made up of 4-inch layers of bluish sandstone. Each bed in 4-inch layers.

TURNER.

All of the deeper wells which have been drilled in the village of Turner have penetrated a bed of more or less thickness of gypsum. The conclusions which have been reached from a few tests have been that the beds were too far below the surface to be of practical use in commercial workings. All of the shallow wells dug in the till contain large boulders of gypsum; out of one well nearly one-half ton of these boulders were taken, showing the abundance of gypsum within the till. The appearance here of these boulders is due to glacial action which scrubbed off masses of rock, in the region of the northeast, where the gypsum outcrops plentifully and were thus carried by the ice in the ground moraines and left in this place.

The water of most of the shallower flowing wells is strongly gypsiferous. The water from the flowing well at the schoolhouse, in Sec. 8, T. 20 N., R. 6 E., which is east of Turner and gives a strong test for gypsum and in drilling it three distinct beds of gypsum were found each three feet in thickness, and the test of this water indicates that the bottom of the well is still in the Michigan series.

Near the corner of Sec. 9, of this same town, Mr. Clukey drilled a 235-foot well and passed 8 feet of gypsum at 95 feet. In Turner, near the Detroit and Mackinac depot, is a well of 300 feet depth and a very strong flow. The record of the well shows gypsum of 5 feet thickness at 64 feet. Mr. M. H. Eymer of this place has a well of 105 feet depth and at 50 feet passed a 12-foot vein of gypsum.

The flowing well drilled on the property of Mr. Swartz penetrated a 15-foot bed of gypsum at a depth of 50 feet, the covering being drift and brown limestone. One mile north of the Swartz property, Mr. Applin drilled a well and obtained a strong flow at 250 feet, striking a 15-foot bed of gypsum at 25 feet.

Several years ago Albert Hann opened a 36-foot pit east of Turner, in the southeast corner of Sec. 8. The pit was opened with the expectation of obtaining a large bed of gypsum near the surface, but the work was finally abandoned for the reason that no bed was found near the surface of sufficient size to be of any value in working. The following strata are quite typical of the underlying rocks penetrated by the wells in this region:—

25 feet boulder clay filled with gypsum and occasional erratic.
3 feet blue, grayish arenaceous shale containing small grains of undissolved gypsum particles.

½ foot of gypsum interseamed with hard brown limestone.
7 feet consisting of hard flinty limestone with many cherty layers and small seams of gypsum.

COUNTY LINE.

Where the Detroit and Mackinac R. R. crosses the east side of Sec. 36, T. 20 N., R. 6 E., the Michigan series are exposed for nearly 200 feet in the sides of the track in the three foot cut made for grade of road bed. The outcrop is covered by the drift in all parts of the near vicinity. The land at this place is formed into a distinct low ridge crossing the R. R. track at right angles and its prominence is perhaps due to the fact that it consists of the hard calcareous sandstone which occurs just above the gypsum at the Keystone dam, Harmon City, and in the small test hole on the property of Albert Hann. The exposed gypsum here is a 6-inch layer and several other layers of hard cherty limestone. The cap of these formations is a hard brown sandstone of a foot in thickness. Along the top of this ridge, which is quite pronounced in direction, would be a place quite suitable for further exploration for the location of a bed sufficient for working on a commercial scale. The well records, especially those of Mr. Applin and Mr. Swartz, are good clues as to what may possibly be expected in the size of bed to be found.

West of the track, near the center of the rather broad, low east and west ridge, Mr. McLean dug a small experimental pit, and from the material thrown out, sandstone was found in abundance, and the gray smooth limestone, both of which closely resemble layers exposed at Harmon City on the shore of Lake Huron, and with these beds are associated a few small layers of gypsum. At the house of S. B. Dwyer, which is west of the R. R. and southwest of the low ridge, a dug well was made into six feet drift through 12 feet shelly brown sandstone and one foot of blue grayish shale.

AU GRES.

The gypsum beds can be clearly traced by wells to the south of the outcropping region as they dip to the center of the basin. This is especially noticeable in the deep wells of the townships of Au Gres and Whitney, in Arenac county. The well on the William French estate, in the northwest part of Sec. 6, T. 19 N., R. 7 E., has a record of 14 feet of gypsum at 100 feet in depth; also the well in Mr. Coles farm reaches gypsum at 80 feet in depth, while south of the village the wells of Mr. Ullman and Mr. Silly penetrate a bed of gypsum at 100 to 115 feet. In the above village some of the shallow wells, like those on the properties of Mr. Grimore, Mr. Bradley, Mr. Badour, show small streaks of gypsum at a depth of 50 to 60 feet.

HARMON CITY.

In Arenac county the point of contact in the Maxville limestone and the Michigan series is on the shore of Lake Huron, 500 feet north of the northeast corner of Section 24, T. 20 N., R. 7 E., and north on the shore of Harmon City. At this point the banks are 15 to 20 feet high. The entire ledge shows the effect of the lake action and the following section is well exposed:

4 feet clay or till.
3 feet red clay, with particles of lime.
1½feet white clay.
3 inches cherty limestone.
5 inches of cherty limestone and sandstone closely interstratified.
1 inch shale and brownish limestone.
8 inches limestone.
6 inches brown sandstone.
4½ feet bluish gray sandstone.
10 inches arenaceous limestone.
5 feet bluish sand.

The strata are quite irregular as the thickness of the limestone varies and, as Winchell has noted, the dip from the point seems to be north and south.

WHITTEMORE TEST HOLE.

Going north 1-8 of a mile on the lake shore from the above outcrop, to the old Whittemore test shaft, we find the limestones are blended into brownish sandstones and the layer of bluish arenaceous sandstone in the stratum of 1½ feet thickness, which is crumpled and folded with thick seams of argillaceous limestone. In this shaft a 10-foot seam of gypsum was reported to have been found, but the project was given up, because of the inflowing water. From this point north on the shore to Alabaster, the lake sand covers all evidences of outcrops. Off shore from this point in 15 feet of water, are seen white beds of gypsum, being part of the lower bed worked at Alabaster and the one penetrated by wells at Au Gres and Turner.

The following are the railroad elevations of this district above tide:

MICHIGAN CENTRAL, MACKINAW DIVISION.

(Old Jackson, Lansing and Saginaw R. R.)

White Feather	604
Saganing or Worth	622
Standish	625
Deep River	657
Sterling	743
Dunham	764
Quinns	784
Alger	782
Culver	787
Summit	829

DETROIT AND MACKINAW RAILROAD.

Station.	Distance from Bay City.	Elevations.
Bay City, Saginaw Bay and Northwestern Branch of the M. C. R. R.	18.6	593.33
Saganing	25.7	592.58
Pine River	29.4	595.58
Omer	34.2	610.94
Twining	39.2	638
Turner	41.5	632
Emery Junction	48.8	672
McIvor	50.6	664
Marks	54.3	644
Tawas City	59.7	587.5
East Tawas	61.0	587.5
Oscoda	74.3	601.5
Alpena	126.0	601.5

May 30, 1901, the lake level was 7.5 feet below track grade at the East Tawas station.

An old profile at the Engineer's office of the Detroit and Mackinac R. R. states that the elevation of grade on the south bank of the Rifle river below Omer is 25.36 feet which equals 20.94 feet carried from Emery Junction. Thus the datum of the line north from Bay City is 4.42 feet higher than from Emery Junction to Omer. This may be accounted for by the fact that the datum from Emery Junction south was five feet lower than the datum of the line from East Tawas to the Junction which was built first and continued to Alger by the Michigan Central. The line from East Tawas to Alger was referred to 580 A. T. (the level of Lake Huron at East Tawas in 1880, and gives Alger, according to the D. & M. profile an elevation of 781 feet which checks with elevation obtained by the Michigan Central for the same place. The line from Bay City north was evidently re-

ferred to 580 A. T., a very meager record of this fact is made in one of the field books of the railroad office and some point of Saginaw River was used as a datum. All of the above elevations are based upon the datum of 580 A. T., for Lake Huron.

DETROIT, BAY CITY AND ALPENA RAILROAD.

This road is now abandoned from Alger to Prescott, the remainder of the original line from Prescott to East Tawas has been consolidated with the Detroit and Mackinaw railroad.

Stations.	
Alger	781
Moffat	769
Shearer	796
Prescott	768
Mills	794
Whittemore	777
Emery Junction	672

The elevations are referred to the datum of Tawas Bay on May 30, 1901, which was taken as 580 A. T. This line of the Bay City and Alpena at one time connected with the Mackinaw Division of the Michigan Central at Alger. The elevation of Alger on the profile of the old line is 781 A. T., which checks with that given to Alger by the Michigan Central.

§ 8. Huron County.

The strata of the Alabaster district pass southeast into Huron county.[1] The sub-carboniferous limestones of the Upper Grand Rapids found in Arenac county are also found with nodules and geodes of chert and quartz and interstratified lenses of coarse sandstone on the Charity Islands and around Wild Fowl Bay. Underneath them are the beds of the Lower Grand Rapids Group, mainly shale with some dolomites and some gypsum, as shown in the geological column of the county given in Figure 10, a reproduction from Plate I, of Vol. VII, Part 2. Upon the geological map of the county, Plate VII, the course of the point where one gypsum bed comes to the base of the drift is outlined. This appears to be well marked by the character of the well water.

Generally, however, there are from 20 to 30 feet of drift. Probably the best chance of striking gypsum under a reasonable cover is along the valley of the Pinnebog near Soule. Compare the wells on Sections 7, 8, 16, and 36 of Chandler Township. Beside these references on pages 182 and 185, see the records at Caseville, pp. 189, 179; Wisner, p.

[1] See report on Huron county, Vol. VII, Part II of these reports.

164, 167; around Tarry in Fairhaven, pp. 161-161, and p. 226. Gypsum evidently extends down into Tuscola county, but I think that going southwest from Huron county we come toward a ridge or anticlinal in the Marshall sandstone which was probably formed during the early carboniferous time before the formation of the gypsum, and served to limit the extent of the gypsum on the southeast side of the coal basin. Here and there are patches of strongly saline shallow wells, but on the whole wells from Vassar and Flint to Bellevue show but little sign of the gypsum formation.

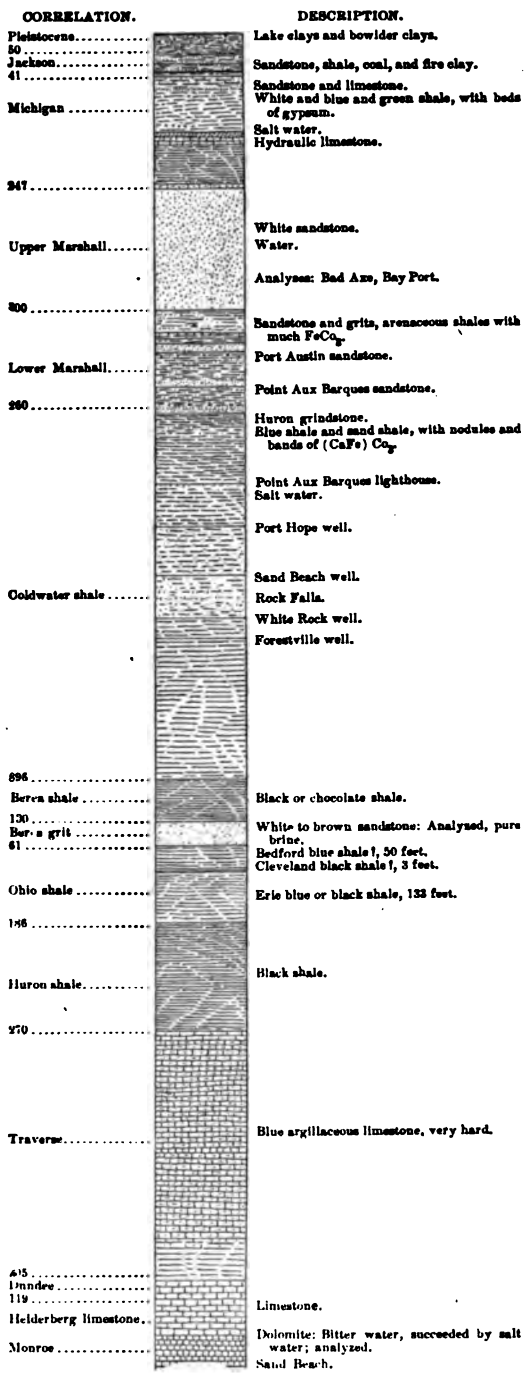

FIG. 10. Geological Section of Huron County

CHAPTER V.

GYPSUM DEPOSITS OF ST. IGNACE.

§ 1. Historical.

The town of St. Ignace is located in Mackinac county on the northern peninsula of Michigan across the straits from Mackinaw City. The narrow peninsula extending southeast from Upper Michigan, terminates in the point of St. Ignace just below the town of the same name. Small capes jut out on the east and west sides of this peninsula, and are known as points. The prominent ones on the west side are, Point Aux Chênes and Point Labarde; and on the east, Gross Point and Rabbit's Back Peak. Plates XXI and XXII.

The narrow gravel and sand beach rises rather abruptly to the upland bluffs covered with pine and poplar timber. The area is traversed by the Duluth, South Shore, and Atlantic railroad, which terminates at the Point and there is connected by ferry with Mackinaw City of Lower Michigan.

The town of St. Ignace extends along the shore and a short distance on the bluffs above. Its history dates far back to the early days of the Jesuits. This place was an early missionary outpost and here is the grave of that famous priest, Pere Marquette.

The bluff above and around the city north and south is composed of heavy ledges of limestone of the Monroe series, which in geological age is Lower Helderberg or Salina. The rocks are covered near the town by a mantle of drift which has disappeared in many places through erosion. It has been an important lumber center and attempts have been made to develop a salt industry. St. Ignace is reached by steamers from Chicago, Detroit, and other lake ports. The distance from Chicago is 330 miles.

An early account of the gypsum deposits at St. Ignace is given by Dr. J. J. Bigsby (the eminent geologist, after whom the Bigsby Medal was named). Dr. Bigsby was surgeon at Fort Drummond and in a paper read Feb. 1st, 1823, entitled "Notes on the Geography and Geology of Lake Huron," published in the Transactions of the Geological Society (p. 193) he says: "At the isles of St. Martin, however, we find a large deposit of gypsum. It is an extensive bed of the granular kind, white, gray, and brown, interspersed with frequent masses of

A. CAR OF GYPSUM COMING OUT OF MINE.

B. ABANDONED ENTRY WITH MUSHROOM BEDS.

red, white, and brown selenite, occurring in shapeless lumps, in veins, or in small and very thin tables, having three or more sides and sharp angles." This account is the first found of the occurrence of gypsum in Michigan.

In the 50's there was a gypsum quarry opened on the west side of the peninsula, seven miles west of St. Ignace near Point Aux Chênes, and a dock was built for loading the gypsum on boats carrying the rock to Chicago, where it was calcined. A scourge of smallpox caused a temporary abandonment of the work, and water in the quarry was a continual source of trouble. It was worked in an interrupted way for a number of years, until an ice gorge carried away the dock and the quarry was abandoned. The property is now owned by Chicago parties. but no work has been done for many years.

About 1894 the Keystone Plaster Co. of Chester, Penn., drilled some test holes two miles west of the old quarry. The records of this work seem to have been lost, but it is stated by some of the men engaged on that work that 60 feet in all of gypsum were found in these wells, and the first ledge of a few feet in thickness was struck under a light cover. No development has followed this drilling.

§ 2. St. Ignace Wells.

In 1888 the Mackinac Lumber Co. drilled a well at the edge of the town of St. Ignace, which was 919 feet deep, and no gypsum was recognized in the upper layers.

Mackinac Lumber Co. Well.[1]

15		sawdust, clay.
485	500	red and blue shales (probably gypsiferous, L.).
400	900	limestone, traces of gypsum.
19	919	sandstone.

The shales, 500 feet thick, belong to the Monroe, and the 400 feet of limestone belong to the Niagara, with possibly the Medina or Hillsboro sandstone below.

A few years ago a new well[2] was drilled two miles north of the old one. This is located in Section 31, T. 41 N., R. 1 E., and about 600 feet north of the town line close to the lake.

[1]Mich. Geol. Survey, Vol. V, Plate LXIII.
[2]Annual Report of Mich. Geol. Survey, 1901, pp. 227, 228.

The record may be summarized as follows:

Pleistocene	34		Surface.
Monroe	11	45	gravel with gypsum.
	129	174	dolomite and shales.
	13	187	gypsum.
	68	255	red and blue shales.
	5	260	gypsum.
	69	329	red and blue shales, gypsum at 300.
	97	426	blue shales, some gypsum.
	18	444	gypsiferous dolomite.
	66	510	dolomite.
Niagara	510	1020	dolomite (water flowing).
	90	1110	limestone.
	56	1166	dolomite.

Some gypsum was found at 35 feet, and 13 feet of gypsum were found at 174 feet, 5 feet at 255 feet depth, and more or less gypsum at other points.

§ 3. Rabbit's Back.

Four miles north of St. Ignace is a prominent spur of limestone bluffs extending into the lake and known as Rabbit's Back. It is clearly visible from the town from which it is separated by a half moon bay. Plate XXII. The bluff, composed of a magnesian limestone, which appears to be unfossiliferous, rises over 200 feet above the lake water, and shows marked effects of erosion. There is practically no drift cover, though granite boulders are common at the foot of the bluffs and on the slopes. A few years ago two kilns were operated here making lime from the stone above.

In 1892, Mr. Chamberlin, the owner of this land, had five holes drilled with a diamond drill under the supervision of Mr. Wm. S. Chalker, who has furnished me with the records of this work.

In well No. 2, the following rocks were found:

23 feet	clay, limestone and some gypsum.
9 "	limestone.
21 "	white gypsum.
3 "	shaly limestone.
9 "	gypsum.

These wells were drilled on the land below the bluffs in an area of 70 acres, and about 10 to 15 feet above the water level in the lake. They all showed about the same order and thickness of the rocks. The gypsum in this point outcrops near the water's edge and can be seen under the water near the shore. At other places it is covered by about 14 inches of dirt.

Drilling was also done on the tract adjoining the Chamberlin land and gypsum was found. It was estimated that the gypsum area in this region would include about 160 acres. Gypsum was found at Gross Point four miles north of Rabbit's Back, and its outcrop is seen near the shore from this point on to the east for several miles. The gypsum

is fairly white, and in places it is spotted with dark selenite crystals rounded in outline.

Similar crystals were found included in some of the Kansas rock gypsum, and their formation was thus explained by Haworth:[1]

"The existence of such phenocrysts (or crystals) indicates that the ocean water was at one time evaporated very slowly, and under the most favorable conditions for the production of individual crystals. Later there was a slight freshening of the water by surface drainage entering the concentrated lake, so that a partial redissolving of the crystals was effected, as shown by the rounded edges of the crystals. Still later there was a rapid evaporation of the water, precipitating the massive gypsum, and an agitation of the shallow water sufficiently vigorous to mix the crystals already formed thoroughly with the new precipitated gypsum, forming the whole mass as it now appears."

§ 4. St. Martin Island, etc.

Some gypsum exploration was carried on a few years ago on St. Martin Island to the east of Rabbit's Back, and the rock shows in the water and was found in shallow wells over a large portion of the southern part of the island. The rock by analysis shows 98 per cent of gypsum, and so contains very little impurity. The records at hand would indicate good deposits which could be worked to advantage if the water could be kept down in the mines at a reasonable cost. The rock on St. Martin Island is stated to be three feet thick in the ledge close to the surface, with other layers further down.

The objections to the St. Ignace gypsum deposits, that they are in thin veins and of poor quality, are apparently untrue. The evidence at hand does not accord with these rumors. The price of fuel might prevent the manufacture of plaster in this section of the State though water transportation is available, but the gypsum might be mined and shipped to other points further south. At the present time there is no development of these gypsum fields. [It is probable that gypsum occurs not far beneath the surface in the northern islands of the Beaver Island group. I have seen many indications of it. L.]

[1]University Geol. Survey of Kansas, Vol. V, p. 59.

CHAPTER VI.

A STUDY OF WELL BORINGS.

§ 1. Preliminary.

A large number of wells have been drilled in this State in search for water, salt, oil, and gas. Many of the records of these wells have not been preserved, but a considerable number have been printed in the reports of the State survey. In these reports it is not always possible to identify the formation. An examination of published records shows the Michigan series identified in 24 wells.[1]

A comparative study of the records preserved will throw some light on the distribution of the Michigan group of rocks, and the places where gypsum[2] is to be found and at what depth. A study of the underlying sandstone will throw light upon the nature of the floor of the old sea, from which the salt and gypsum were precipitated.

The gypsum deposits of Michigan at Grand Rapids and Alabaster are found in the Grand Rapids division of the Michigan group, which is Carboniferous in age. The deposits at St. Ignace are in the Salina formation. In the wells in Monroe county and some others in the State gypsum is found in this same formation. The first division of this chapter will be devoted to the study of the gypsum in the Carboniferous, and the second to the deeper deposits of the Salina.

In most of the wells, the first formation on the surface is the drift, consisting of sands, clays, and gravel. The records which follow have been taken mainly from the published reports of the Michigan survey, but have been condensed and adapted to the present purpose. The levels given are railroad levels of the nearest points, and so are not always accurate for the top of the well.

§ 2. Carboniferous (Grand Rapids Group) Gypsum.

The distribution of the Grand Rapids group below the surface can-

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[1]Viz.: Alma, Vol. V, Pt. 2, p. 45. Vol. VIII, Pt. 2, p. 175: Bay City, Vol. V. Pt. 2, Plate VI, and annual for 1901: Caseville, Vol. V. Pt. 2, p. 53: Vol VII Charlotte V, Pt. 2, VIII; Corunna V, Pt. 2, Plate XII: East Saginaw V. Pt. 2, p. 55: South Saginaw and the Bliss well, VIII, Pt. 2, p. 176: Grand Rapids V. Pt 2, p. 61: Kawkawlin V, Pt. 2, p. 65: Midland V. Pt. 2, p. 69, VIII, Pt. 2, p. 163; Sebewaing VIII, Pt. 2, p. 172; St. Charles VIII, Pt. 2, p. 192; St. Johns VIII, Pt. 2, p. 196; Durand VIII, Pt. 2, p. 199: Mason VIII, Pt. 2, p. 217.

[2]It is worth noting that microscopic observations lead me to believe that all the calcium sulphates below, say 500 feet, is really in the denser form of anhydrite and water rather than gypsum. This is to be understood in reading the description. When anhydrite is mentioned it is because I have actually recognized it as such under the microscope. I have also inserted some newer data regarding Mt. Pleasant, Detroit, Wyandotte, Milan, Ludington, Muskegon, etc. L.

not be described over very much of the State of Michigan on account of the small number of well records available. The farthest north this group is found in recorded wells is at Grayling in Crawford county, 125 miles northeast of Grand Rapids. The formation in the Grayling well consists of sandstone, limestone, shales, and gypsum, 175 feet thick as compared with 177 feet in the Lyons well at Grand Rapids. The gypsum is 408 feet from the surface, where the level above tide is about 1,135 feet. It is reported as 132 feet thick, but there is but one sample, and this is doubtless incorrect and the thickness includes shales. This record would place the gypsum 727 feet above sea level, while at Grand Rapids it is 530 feet in the Lyons well. At Grayling the Grand Rapids group rests on the Coldwater shales.

A general theoretical section of the Lower Michigan rocks is as follows:

		Feet.
Drift		3 to 60
Saginaw (Jackson) Coal Group (Upper Carb.)		50
Parma	" "	100
Grand Rapids Group	Lower "	300
Marshall sandstone	(Waverly)	75
Coldwater shales, etc.	(Waverly)	800
Berea sandstone	(Waverly)	65
Antrim shales (Devonian)		225
Traverse Group (Hamilton)		350
Dundee limestone (Devonian)		100
Monroe beds (Lower Held. and Salina)		700

The Grayling well record may be summarized from the Annual Report of Michigan Geological Survey, 1901, page 232, as follows:

Drift	365 feet		drift gravel, etc.
Lower Grand Rapids	380 "	15	calciferous sandstone.
	408 "	28	dark limestone.
	540 "	132	gypsum and shales.
	960 "	420	blue shale.
Coldwater	1150 "	190	limestone.
	1540 "	390	blue shale.
Berea (?)	1590 "	50	red and blue shales.
Devonian	2750 "	1160	shales and limestone.

On the eastern side of the Lower Peninsula are found the records of the East Tawas well, those of Huron county already referred to, and the group of Port Huron wells at New Baltimore, St. Clair and Marine City. In the Port Huron group of wells, the Pleistocene rests on the Devonian, with no traces of the Carboniferous strata. The gypsum (anhydrite) comes from the Monroe (Salina) rocks. At East Tawas 50 feet of drift rests on the Marshall sandstone with no traces of the Grand Rapids group. In the Sebewaing well of Huron county, 56 feet of drift rests on 44 feet of the coal measure sandstone and shales. The Grand Rapids group, 100 feet below the surface, consists of shales and limestone with no gypsum beds, and rests on the Marshall sandstone, which is 248 feet below the surface. (See the Huron county

report, Volume VII, Part 2.) But the wells for Terry, the next station, and thence north, show more or less gypsum.

In the Saginaw and Bay City area there have been numerous wells drilled in search for salt, and out of the large number a few records are available. At Bay City the Grand Rapids group lies below 100 feet of drift and 465 feet of Jackson coal shales. It consists of limestone, sandstone, shales, and gypsum in a 12 to 15 foot layer. The gypsum is 712 to 720 feet below the surface and 128 feet below sea level. Below the Grand Rapids group comes the Marshall sandstone and Coldwater shales.

The Bay City well record (a newspaper record) given in Volume V, is as follows; down through the Grand Rapids series:

Drift	120	120	
Saginaw coal measures	444	565	
Grand Rapids series	20	585	limestone, 85% brine.
	50	635	sandrock.
Lower Grand Rapids or Michigan	25	660	sandy shale.
	40	700	blue shale.
	12	712	gypsum,[1] white 6-inch casing to 722 feet.[2]
Marshall, upper	108	820	blue shale.
	10	830	hard limerock.
	80	920	sandstone, brine 100.°
Marshall, lower	135	1055	red and white shale and so on down to 2865 feet.

The well at the North American Chemical Co.'s works, So. Bay City, was given in the Annual Report for 1901, p. 224, as far down as the Marshall, and is as follows, revised:

Drift	105	105	sand, clay, etc.
Saginaw coal measures	385	490	shale, quicksand, and salt.
Parma ?	50	540	sandstone pyrite at top.
Upper Grand Rapids	80	620	limestone.
	5	625	sandstone.
	5	630	limestone.
Lower Grand Rapids	30	660	shale.
	10	670	gypsum, etc.
	30	700	limestone 10, shale 10, sandstone 10.
	7	710	gypsum (compare 712 of 1st well).
	10	720	" and limestone.
	10	730	" " shale.
	70	800	shale and limestone.
	10	810	limestone, gypsum shale.
	20	830	limestone and shale.
	20	850	pyritic limestone.
Upper Marshall, Napoleon	120	970	water-bearing sandstone.
Lower Marshall	225	1295	sandstone and shale largely red.
Coldwater.	2050	760	shales. Goes on down to 3508 feet.

[1]Or anhydrite.
[2]Compare with Saginaw wells, like Whittier's No. 3, which when about 740 feet deep was cased down to 551' 2".

It appears that beside other gypsum beds, one near the bottom, there is a quite persistent bed 130 feet or so above the bottom. A bed in a similar position is found in Huron county, at Midland, Alma, and Mt. Pleasant, so that it is probably quite persistent.

At Kawkawlin, just north of Bay City, the drift is 100 feet thick and the Jackson Coal group 300 feet. Gypsum was found at 400 feet and the thickness of limestone and gypsiferous shales was 100 feet. This record is incomplete, but probably shows the Marshall sandstone below. The gypsum is 196 feet above sea level, and farther north at Alabaster it is about 600 feet above the sea.

Abstract of Kawkawlin Well, Bay County.

Michigan Geol. Survey, Vol. V, p. 65.

Drift	100		drift.
Jackson Coal Measures	400	300	shale, sandstone, coal seams.
Grand Rapids Group	500	100	limestone, shales, gypsum at 400 feet.
	700	200	gypsiferous shales.
Marshall ?	800	100	sandstone.

Abstract of South Saginaw Well.

Michigan Geol. Survey, Vol. VIII, p. 176.

Drift	340		Drift.
Saginaw Coal Measures	493	153	sandstone, shale.
Upper Grand Rapids Group	525	32	sandy limestone.
	555	20	impure sandstone.
Lower Grand Rapids or Michigan	570	75	calcareous green shale.
	665	95	green shale.
	690	25	argillaceous dolomite.
Marshall	715	25	sandstone.

At South Saginaw the Grand Rapids group is 493 feet below the surface or 95 feet above sea level and consists of limestones and shales, and the same order seems to hold in the East Saginaw well, where the group is 398 feet below the surface and consists again of sandstone and shales, with some limestone and no beds of gypsum mentioned.[1]

East Saginaw Well.

Michigan Geol. Survey, Vol. V, p. 55.

Drift	92		drift.
Saginaw Coal Measures	398	206	alternating sandstone and shale.
Grand Rapids Group	462	64	alternating limestone and sandstone.
	634	172	alternating shale and sandstone.
Marshall ?	797	163	sandstone.
	800	3	bright red shales.

[1] Though from the casing down to cut off the gypsum bearing brines it is probable that more or less is present, and Mr. John Coryell tells me that such is the case. For instance the Whittier well at Florence 740' 11" deep was cased with an offset down to 551' 2" to keep out the gypsum, or gypsiferous brine. L.

In the next county of Midland, west of Bay City, a five and one-half foot layer of gypsum was found in the Sanford well 134 feet below the surface. An occurrence similar to that at Sanford appears to be that at Fremont township in Saginaw county. The age and occurrence of this Sanford gypsum and that of Fremont are very uncertain. I am tempted to believe they may be boulders in the drift, but it is also possible that they may represent interglacial or preglacial deposits derived from the erosion of Alabaster gypsum deposits. It is worth noting that boulders of gypsum are not uncommon southwest of Alabaster, as at Alma and Mt. Pleasant, and water of wells in the drift are very strong of sulphates.

Wells in Fremont and Brant townships, towns. 9 and 10 N. R. 2 E. also often show gypsum. The following records were collected by W. F. Cooper. "Mr. D. Steele, on the half of the west side of Section 33, Fremont township, has flowing wells 70 to 80 feet deep. There was said to be 25 feet and more of gypsum in this well. The record was also given by A. McPhee, the driller, as:

Clay	7	7
Clay and boulders	25	32
Sand and gravel	25	57
Hard pan (till)	12	69
Clay and gravel	1	70
Gypsum	18	88

Mr. A. McPhee, opposite on the east side of Section 32, reports a flowing well 107 feet deep with 7 feet of gypsum, at the bottom, till above. These wells were started as coal tests, and I have seen samples of the gypsum obtained, and also talked with the intelligent business men F. G. Benham, Barnes, Linton, etc., of Saginaw, for whom they were drilled. Two or three of the wells were put down and they are of the opinion that the gypsum is continuous, but a part of the drift. Of course, without a roof and in an artesian basin it is not mineable." A few miles to the south in the Midland well, the gypsum bed described as nearly pure anhydrite, 80 feet thick,[1] was 970 feet below the surface. In the later well the Grand Rapids group was 285 feet thick and consisted of limestone, calcareous shale, and anhydrite resting on the white sandstone of the Marshall formation.

Sanford Well.

Michigan Geological Survey, Vol. VIII, p. 164.

Drift	134		alternate sand and clay.
Grand Rapids Group	139½	5½	gypsum.
	240	100½	alternate sand and clay.
Marshall	254	14	white sandrock.

[1] But samples are not numerous.

MULES IN GYPSUM MINES.

Midland Well.

Michigan Geological Survey, Volume VIII, p. 163.

Drift	285		drift.
Saginaw Coal Measures	920	635	sandstone, shales.
	970	50	limestone.
Grand Rapids Group	1050	80	plaster red, fairly pure anhydrite.
	1130	80	calcareous shale.
	1205	75	limestone.
Marshall	1305	100	white sandstone.

To the south of Saginaw, in Shiawassee county, there are three records available. In the Owosso well the Grand Rapids group was found 473 feet below the surface and 272 feet above the sea. It consists of 83 feet of limestone, shales and thin beds of limestone, and it contains salt water but no beds of gypsum. In the Corunna well the Grand Rapids group was found at 649 feet, or 127 feet above sea level, and included 152 feet of sandstone and shales with no beds of gypsum.

Corunna Well.

Michigan Geological Survey, Volume V, Plate XII.

Drift		30	drift.
Saginaw Coal Measures	225	255	alternate shales and sandstone.
Parma	649	394	sandstone.
Grand Rapids Group	706	57	sand, shales.
	738	32	blue shale.
	743½	5½	sandstone.
	744	1½	black shale.
	745	1	shale.
	755	10	sandstone.
	765	10	shale.
	800	35	sand, blue shale.
Marshall ?	907	107	sandstone, shale.

Owosso Well.

Michigan Geological Survey, Volume V, Plate XLV.

Drift		100	drift.
Saginaw Coal Measures	301	201	clays, shale, sandstone, coal.
Parma	473	172	sandstone.
	476	3	limestone.
Grand Rapids Group	533	57	blue shale.
	536	3	brown limestone.
	541	5	salt (water ?).
	556	15	soft shale.
Marshall	601	45	sandstone and salt water.
Coldwater	716	115	shale, sandstone, salt water.
	1000	284	shales.

The Durand Well, given in Volume VIII, Part II, p. 199, is not safely to be interpreted. No gypsum was recognized by the drillers. It is said to be mainly shale below the drift.

West of Saginaw, in Gratiot county, at Alma, the Grand Rapids group is found in 790 feet and consists of 225 feet of shales and shaly limestone with beds of blue and white gypsum at 860 feet or 105 feet below sea. This is the second record showing the gypsum below sea level, the other being the Bay City well described above. Calcium sulphate occurs at Mt. Pleasant and St. Louis, being probably anhydrite in all these wells. An analysis of the drillings from the Mt. Pleasant well gave M. A. Cobb of the Lansing high school:

	Per cent.
Fe_2O_3, Al_2O_3	1.4
$Ca\,C\,O_3$	2.83
MgO	.2
$CaSO_4$	87.15
SiO_2, CO_2 and Moisture	8.42
	100.00

Alma Well.

Michigan Geological Survey, Vol. VIII, p. 175.

Drift		475	drift.
Saginaw Coal Measures	790	315	shales, sandstone, some coal.
Grand Rapids Group	860	70	blue and black sandy shales.
	895	35	blue and white (anhydrite) gypsum.
	1015	120	argillaceous limestones.
Marshall	1500	485	sandstone and shale.
Coldwater	2250	750	shales.
Berea shale	2300	50	black shales.
Berea grit absent.	2360	60	blue shales.
Antrim shales	2750	390	black shales.
Traverse	2861	111	limestone and shales.

Good samples of the new wells for bromine of the Midland Chemical Co., at Mt. Pleasant, were saved. The elevation of the well is about 770 A. T., and the anhydrite is most abundant from 450 to 600 feet down, the record of the well being:

Drift.		
80	80	gravel, glacial overwash.
20	100	blue till.
20	120	quicksand.
160	280	blue till.
74	354	porous bed with water, coarse gravel on top, fine sand below.
26	380	red clay.
55	435	ground moraine till with broken coal measures.

Saginaw Coal Measures.		
185	620	black shale with streaks of coal (410′, 435′, 460′) sandstone, limestone, or carbonate of iron and fire clay, mostly less than five feet thick.
90	710	Fine white sandrock with mineral water.
80	790	gravelly sandrock with a strong flow of water, not so salt.
30	820	shale and red limestone.
Parma and Maxville.		
30	850	white limestone.
120	970	white sandstone with very salt water.
55	1025	white limestone fiercely effervescing.
Lower Grand Rapids or Michigan Series.		
5	1030	shale.
20	1050	sandstone.
75	1125	dolomite and shale.
100	1225	anhydrite and dolomite.
45	1270	" nearly pure (gypsum).
103	1373	dolomite, shale and anhydrite.
8	1381	sandstone.
5	1386	shale.
4	1390	sandstone.
15	1405	shale.
160	1565	sandstone, dark with heavy brine.

To the south of Charlotte, in Eaton county, I recognize, in Vol. V, the Grand Rapids group, with some doubt. Only a few samples were saved, and those do not show any typical beds, though the Upper Grand Rapids or Maxville limestone crops out just south at Bellevue. It may be absent, for we are approaching the margin of the basin where there are variations due to irregular erosion.

A deep well at Assyria, 917 A. T. (Sec. 4 T. 1, N., R. 7 W.) shows two samples which were supposed to represent the rock from the bed rock surface at 162 feet to 240 feet, which are typical of the Michigan series, dark colored dolomites, with greenish shale and some selenite.

The reference of part of the Ann Arbor well to the Michigan series, by A. Winchell,[1] is certainly erroneous, and I am inclined to think that in the records of Jackson wells, given in Vol. V, the Grand Rapids group may be really absent, the heavy sandstone beneath the coal measure representing the shoreward coming together of the Marshall and Parma, as explained in Vol. VIII, Part 2, pp. 39 to 40.

The Ludington well, given as Plate XXIX of Vol. V, is an error. Mr. E. D. Wheeler says it is merely his correlation of their Manistee well. It may have been used in Ludington as a guide to the driller in putting down their well. A well was recently put down by the J. S. Stearns Lumber Co., and a good set of samples saved for us. A limestone facies like that of the Grand Rapids occurs between 576 and 650 feet, but similar rocks with some selenite occur in Muskegon wells, for instance, that of the Central Paper Co. from 625 to 850 feet down, which appears to be distinctly in the Coldwater series. I take it, therefore, that there were forerunners of the Michigan series formed

[1] Vol. V, pt. 2, p. 48.

somewhat earlier along the margin of the Michigan basin, as a facies of the Coldwater series.

§ 3. Well Records Near Grand Rapids.

In the area near Grand Rapids there have been in past years a number of wells drilled in search for salt. Most of these wells start on the Grand Rapids group or pass into this formation through a shallow drift cover. These wells were drilled from 1840 to 1860, and the records carefully preserved by Prof. Winchell. In the so-called artesian well the plaster rock was found 57 feet below the surface and mixed with clay shales. The Lyons well record is given in a very detailed section and shows alternating shales, sands, and gypsum of the Grand Rapids Group resting on the Marshall sandstone. In the State well the gypsum was 40 feet below the surface. In the Scribner well the stratum appears to be replaced by gypsiferous shale and the same is true in the Powers and Martin wells, one-half mile north of the Scribner well.

Artesian Well Co. Well.

Michigan Geological Survey, Vol. V, Plate XX.

Drift	10		drift.
	57	40	black shale.
Grand Rapids Group	128	71	plaster rock, shale.
Marshall	259	131	sandstone.
Coldwater	1175	916	shales, sandstone.
Berea	1205	30	sandstone.
Antrim	1708	503	shales.
Traverse	1885	177	shales 67 feet and dark limestone.
Monroe	2200	315	limestone, light above, dark below.
	2.20	20	gas, marl, limestone, brine.

A record of the same well furnished by the Godfrey Estate.

10		gravel, clay.
127	118	gypsum and shales.
145	17	limestone.
240	95	sandstone.
259	19	"
271	12	blue clay shale.
400	129	sandstone.
702	302	shales.
712	10	limestone.
1155	443	shales.
1175	20	red clay.
1205	30	sandstone.
1775	570	shales.
2220	445	limestone.
2340	120	limestone, sandstone, with salt.

State Salt Well.

Report of Winchell, 1860, p. 144.

Drift	40		drift.
Grand Rapids Group	47	7	gypsum.
	48	1	limestone.
	61	13	clay, shale.
Marshall	473	412	clays, shale, sandstone.

Grand Rapids No. 2 or Lyons Well.

Michigan Geological Survey, Vol. V, Plate XXI.

Grand Rapids Group	14		hard gray limestone.
	20	6	sandstone.
	30	10	blue clay.
	41	11	clay with gypsum
	59	18	clay shale.
	63	4	gypsum.
	65	2	clay shale.
	71	6	gypsum.
	74	3	clay shale.
	82	8	blue sandstone.
	100	18	blue clay.
	107	7	sand and clay.
	117	10	limestone, gypsum.
	124	7	gypsum.
	133	9	clay shale.
	140	7	sandstone, clay.
	147	7	gypsum.
	153	6	clay shale.
	172	19	gypsum shale.
	175	3	gypsum.
	180	5	clay, sand gypsum.
	191	11	clay rock.
Marshall	265	74	sandstone.

Scribner's Salt Well.

Winchell Report, 1860, p. 146.

Grand Rapids Group	51		limestone.
	52	1	compact shale.
	54	2	blue limestone.
	204	150	shales, lime, sandstone, gypsiferous.
Marshall	315	111	sandstone.
	325	10	clay.
	380	55	sandstone.

Powers and Martin Salt Well.

Winchell Report, 1860, p. 147.

16		surface.
56	40	limestone.
97	41	shale, clay.
98	1	clay, streaks of gypsum.
116	18	shale gypsiferous.
120	4	shale.
136	16	gypsiferous shale.
138	2	sandstone.
156	18	shale with gypsum.

Indian Mill Creek Salt Co. Well.
Winchell Report, 1860, p. 149.

Drift	81		gravel, sand.
	84	3	white gypsum.
	92	8	clay, shale.
Grand Rapids Group	96	4	hard rock.
	130	34	clay.
	137	7	sandstone.
	141	4	clay.
	157	16	gravel.
	161	4	sandstone (bottom of Power's well).
	203	42	gypsum, clay.
	319	116	sandstone.
	334	15	clay and shale.
Marshall ?	424	90	sandstone.
	434	10	clay, sandstone.

Butterworth Salt Well.
Winchell Report, 1860, p. 148.

Grand Rapids Group		12	limestone.
		5	sandstone.
		1	limestone.
		1	clay shale.
	24	5	limestone.
	27	3	calcareous sandstone.
	57	30	clay, limestone.
	61	4	brown limestone.
	122	61	shales with gypsum.
	184	55	lime. gypsum.
Marshall ?	293	109	sandstone.
	303	10	shale.
	431	128	sandstone, shales.
	490	59	shales, sandstone.

Windsor Salt Well.
Winchell Report, 1860, p. 150.

Drift	43		drift.
Grand Rapids Group	64	21	limestone.
	72	8	dark shale.
	76	4	sandstone.
	88	12	shale, gypsum.
	89	1	sandstone.
	99	10	shale, gypsum.
	108	9	greenish clay, shales.
	132	24	gypsum, shales.
	152	20	blue and black shales.
	156	4	gypsum.
	166	10	black shale.
	179	13	gypseous clay, very salty.
	183	4	black hard rock.
	240	57	dark flint clay, gypsum.
	248	8	pyritiferous rock with gypseous clay.
Marshall	327	79	sandstone.
	349	22	clay, sandstone.
	423	74	sandstone.
	446	23	argillaceous sandstone.

Beyrich Brewery Well.

Michigan Geological Survey, Vol. III, p. 110.

Drift	35		drift.
	36½	1½	limestone.
	43½	7	blue shales.
	45	1½	gypsum.
	124½	79½	shales, pyritiferous rock.
	129½	5½	sandstone.
Grand	134½	5	gypsum.
	135	½	sandstone.
Rapids	137½	2½	shale.
	142½	5	gypsum.
Group	147	4½	blue shale.
	147½	½	hard flinty rock.
	153½	6	gypsum.
	158	4½	blue shale.
	166	8	pyritiferous rock.
	221	55	white sandstone.
	227	6	blue shale.

In the Windsor well north of the city about 30 feet of gypsum in all was found and the first was struck at 76 feet or 529 feet above sea level. In the Butterworth well in the city, the first gypsum was found at about 70 feet or 533 feet above sea. In the Lyons well in the city 40 feet of gypsum were found and the first at 545 feet above sea. The wells south of the city, the State Salt well and the Godfrey well, reached the gypsum at 596 and 620 feet A. T.

These wells, studied in connection with the quarry exposures of gypsum, show that the gypsum surface is exceedingly irregular. It is highest north of the river and lowest in the city and north of the city. South of the river the gypsum dips northeast about 40 feet from the quarries south of the city to the wells in the city, or about 25 feet to the mile. The gypsum surface in the city and north beyond the city limits in the Windsor well appears to be almost level. If it ever seemed advisable to mine this gypsum in this area there would be trouble with water which would have to be removed by strong pumps.

§ 4. Drilling by the Pittsburg Plate Glass Company.

In the spring of 1902 the Pittsburg Plate Glass Co., having secured a tract of land north of the Grand River and west of Grand Rapids, drilled six wells in search for the gypsum rock (see Plate XVII). The results of this work have been kindly furnished to the writer by this company, and the following account is based on the careful notes of their engineer, Mr. J. J. Mears of Grand Rapids.

The work demonstrated the existence of a good stratum of gypsum suitable for the manufacture of plaster, but the company decided not to develop the tract at the present time. The well records show the clay, shales, limestones, and some sandstone of the Grand Rapids series.

Well "A."

78		sand and clay.
80	2	shale.
85	5	flinty clay.
88	3	gypsum.
91	3	shale.
94	3	sandstone.
95	1	shale.
105	10	gypsum.
110	5	shale.
114	4	gypsum.
115	1	sandstone and gypsum streaks.
121	6	gypsum.
123	2	shale.
130	7	gypsum.
135	5	shale.

Well "B."

77		sand, clay, gravel.
78	1	shale.
82	4	gypsum.
83	1	clay.
85	2	gypsum.
89	4	shale.
90	1	gypsum.
95	5	shale.
96	1	gypsum.
100	4	shale.
101	1	gypsum.
103	2	shale.
104	1	flint.
108	4	sandstone.
117	9	gypsum.
119	2	limestone.
123	4	shale.
135	12	gypsum.
136	1	blue clay.

Well "C."

64		sand and gravel.
67	3	shale.
69	2	gypsum.
75	6	shale.
77	2	gypsum, limestone. (abandoned)

Well "D."

68		gravel, sand.
71	3	shale.
72	1	gypsum.
84	12	shale, some gypsum.
86	2	gypsum.
98	12	shale, some gypsum.
99	1	limestone.
103	4	shale.
117	14	gypsum.
130	13	shale, some gypsum.

Well "E."

24		sand.
61	37	shale.
64	3	sandstone.
69	5	shale.
74	5	sandstone.
77	3	shale.
92	15	gypsum.
92½	4	inches, shale.
96	4	gypsum.
98	2	sandy shale.
104	6	gypsum.
	6	inches shale.
107	3	gypsum.
110	3	sandstone.
112	2	shale.
116+	4+	gypsum.

Well "F."

106		sand, gravel.
115	9	shale.
122	7	gypsum.
123	1	clay, pyrite.
136	13	gypsum.
138	2	shale.
141	3	gypsum.
143	2	shale.
147	4	limestone.
149	2	gypsum.
150	1	limestone.

In well "A" the ten foot ledge of gypsum was found at 95 feet or 574 feet above tide. In well "B," about 100 yards east of "A", the 12 foot vein was 123 feet below the surface, or 613 feet A. T.

In well "D," one-fourth of a mile north of "A," the 14 foot stratum of gypsum was reached at a depth of 103 feet or 594 feet A. T. In well "E," 200 yards southwest of "A," the 15 foot ledge was struck at 77 feet or 565 feet A. T. In the well "F," one-half mile north of "B," the 13 foot gypsum stratum was found at 123 feet or 609 feet A. T.

These records give a dip of four feet north in one-half mile or eight feet to mile from "B" to "F." The extremes of variation are shown in wells "B" and "E," giving a difference of 48 feet in about 600 feet.

A. DURR PLASTER MILL, GRANDVILLE.

B. GYPSUM QUARRY OF DURR MILL, AT GRANDVILLE.

These drillings prove the gypsum to extend over the area to the west and northwest of the gypsum mines now opened north of the river. This field will doubtless be opened before many years, adding to the production of the plaster in the Grand Rapids area.

§ 5. Gypsum in Wells Reaching the Silurian.

The gypsum deposits in the Monroe or Salina near St. Ignace are the only ones in this formation in Michigan found near enough to the surface to afford any encouragement for working. Possibly the northern islands of the Beaver Island group would find it a short way down. In most of the deep wells of the State around the border of the coal basin, gypsum or rather anhydrite is found in this same geological formation.

In the Niles well in Berrien county, in the southwestern part of the State, a 20 foot stratum of anhydrite and gypsum was found in the Monroe formation at 615 feet from the surface down to 720 feet. At the east gypsiferous shales were struck at 648 feet in the Port Huron well.

Gypsum, or rather anhydrite, occurs in the Benton Harbor well at 815 feet, and in the Kalamazoo well at 1,500 feet, in the Manistee well at about 1,800 feet, in the Marine City well at 1,400 feet, in the Mt. Clemens well at 980 feet, in the Muskegon well at 2,350 feet. Gypsum occurs in the wells of the Edison Illuminating Co., near Ft. Wayne, Detroit, on down from 900 feet, in the Wyandotte wells from 590 feet down (especially at 750 feet), near Trenton from 690 feet down, at Ludington about 2,050 feet, at St. Clair at 1,510 feet, at Milan, 1,050 feet (at 1,210 feet very solid). All these deposits were in the Monroe or Salina formation.

The total quantity of calcium sulphate in the rocks of Michigan, from the surface Carboniferous to the deep Niagara, must be very great, but the deep strata of anhydrite are of only scientific interest and not of present economic importance.

§ 6. Conclusion.

A comparative study of these well records, from the various localities of the Lower Peninsula, shows that the gypsum is found in the wells on the eastern and western sides of the interior coal basin and at the north in the Grayling well. In the wells in the interior gypsum is replaced by anhydrite. The gypsum was evidently deposited on the borders of the old interior sea.

The depth of the anhydrite in most of these wells (Bay City, 700 feet; Kawkawlin, 400 feet; Midland, 970 feet; Alma, 895 feet; Mt. Pleasant, 1,125 feet), would be too great to make any mining profitable. Moreover it is a question just what treatment would be needed to make anhydrite (which corresponds to a dead burnt plaster) set.

The industry will be confined to the eastern and western parts of the Peninsula, to Alabaster and vicinity at the east, and to the area around Grand Rapids at the west. New borings and extensions will doubtless increase the productive areas in these two localities as illustrated by the recent work of the Pittsburg Plate Glass Co. at Grand Rapids.

§ 7. Total Quantity of Gypsum Available in Michigan.

On account of the irregular distribution of gypsum, being cut out here and there, and the uneven thickness, and the few borings recorded, it is impossible to give any accurate figures as to the amount of gypsum present in the two localities where it is now worked.

There are approximately six square miles of gypsum area near Grand Rapids, with an average thickness of 10 feet. A cubic foot of gypsum weighs 140 pounds, so this area would yield nearly 118,000,000 tons of gypsum, which would make about 100,000,000 tons of plaster. This quantity would supply the whole United States for 170 years or more at the present rate of consumption. The Alabaster field would yield about 20,000,000 tons, not counting unprospected areas west. But little can be said as to the areas in Huron county and around St. Ignace. The amount of gypsum or anhydrite shown by the deep drill records would have to be reported in billions of tons. While these figures may be too high, they are yet of value in giving some idea of the quantity of available supply, even if the actual prospecting work should cut them down.

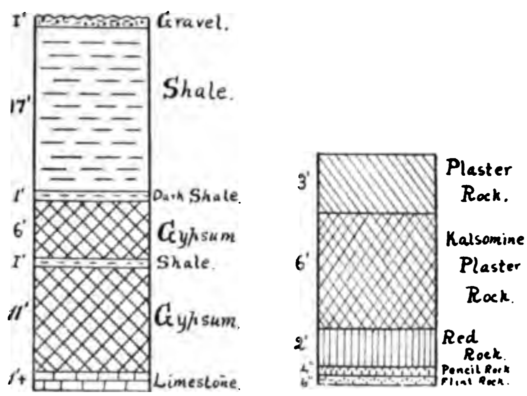
CHAPTER VII.

MICHIGAN MINES AND MILLS.

§ 1. Grand Rapids District.

THE ALABASTINE COMPANY.

The gypsum mine of the Alabastine Co. was opened in 1876, at the present locality, two miles south and one mile west of the center of the city of Grand Rapids. It is just outside of the city limits in the northwestern quarter of section 2, Wyoming township, three-quarters of a mile south of the Grand river and on the Pere Marquette and Pennsylvania railroads. Plate V.



a. b.

FIG. 11. Section in Alabastine quarry. also (b) one showing uses.

A geologic section at the mine is represented in Figure 11. The gravel cover is usually shallow and will average about one foot over the bluish shales which weather to a buff color and are 12 to 17 feet in thickness. Between this shale and the six foot ledge of gypsum is one foot of dark shale of very different character from the buff shale which makes poor brick and cement. As the buff shale is used for cement manufacture, this dark shale represents the waste in stripping. The six foot gypsum layer is separated from the so called 12 foot layer (in reality 11 foot) by about one foot or less of shale. The bottom rock of the quarry is a com-

pact bluish gray limestone which in places is distinctly banded and on weathering becomes soft and shaly. It seems to contain a considerable amount of alumina or clay.

The gypsum is worked in an open quarry by stripping off the overlying shales, and the lower 12 foot ledge is the one used at the present time. This ledge while slightly furrowed by solution on the top is approximately level and has probably been protected from marked solution by the overlying gypsum and the compact shale. The ledge is marked by two thin clay seams, one about three feet from the top and another about two feet below this, which run into slightly wavy lines through most of the quarry and represent a slight change in conditions at the time the gypsum was deposited, a slight interruption in the precipitation, possibly by inflowing water bringing a slight amount of sediment, or by the action of the currents distributing some foreign material.

The base of the gypsum for two feet from the bottom is colored red or pink and rests on a peculiar *cone in cone* red gypsum layer four inches thick, called pencil rock by the quarryman. In many quarries crystals of selenite are found, but in this quarry I found no traces of crystals, though some imperfect crystals have been found but these are rare. No specimens of white fibrous satin-spar were found, though the cone in cone structure may represent a variation of the fibrous satin-spar, as explained in the section on the Grandville quarry. A well defined jointing plane runs east and west through the south side of the quarry and stands out clearly on account of its very smooth face exposed for a distance of 200 feet. Minor jointing faces extending a short distance are also found in the quarry.

At the north side of the quarry the gypsum is entirely cut out for a space of 100 feet east and west and running off to the north. The space is filled with clays similar to those found above the gypsum. No stratification is seen in the clay, and it has probably settled as the gypsum was removed by solution. The gypsum abutting this clay is worn into furrows and ridges of irregular course, several inches in depth, clearly the result of water action. In no part of the quarry are evidences of solution more marked. It would seem as though there must have been at a former time an underground water channel running through this part of the quarry to the north, but there is no evidence of its existence to the south in this quarry. Further evidence of the existence of this channel is found near the mill. In constructing the foundation for the large brick stack, one-half was built on gypsum rock, and the north half on clay with no trace of rock. Drillings made to the south of the quarry and on the hill to the east of the mill show a good gypsum ledge. To the north of the quarry and west of the mill, borings fail to find gypsum. To the northeast across Plaster creek is the Godfrey quarry, where the gypsum is

found in good thickness. Another possible course of this underground channel is suggested from the experience in the old quarry.

It is said that the lower edge of gypsum disappeared to the west in the working of the old quarry near the Grandville road in 1876, and caused the abandonment of that quarry and the opening of the new one. This old quarry is now filled with water so this account was not verified by the writer. Borings on the west side of Plaster creek between the two quarries are reported to show no gypsum. Granting the truth of these observations, the failure to find gypsum may represent the discovery of an old water course passing to the northwest from the old to the new quarry and then turning to the northeast past the mill. Not enough boring records are available to map in detail such a water course, or even to prove its existence beyond a possible doubt.

The upper gypsum ledge, six feet thick, is exposed for several hundred feet in the south side of the quarry, but disappears both to the east and west within the limits of the quarry. To the west where it has disappeared as a well marked ledge, boulders of gypsum, very much water worn, are scattered through the clay shales. On the west and north sides of the quarry, no trace of the upper ledge is seen, though it again appears in the Godfrey quarry, less than a mile to the northeast, and it is found in the workings north of the river. The gypsum in this area south of the river shows in this marked degree the effects of past solution through water action, so that the quarry men follow the rule that "gypsum is only found where you find it."

The work in the quarry at the present time is at the western and northwestern ends. The overlying shale was formerly burned into brick in the company's brick plant located to the east of the gypsum mill. This made a very good quality of red brick, some of which was used in the construction of the new mill. As the quarry was worked farther and farther west, the hauling of the clay became more expensive; and as the new Portland cement mill at Newaygo found this clay and shale especially adapted to their work, they made arrangements to obtain it and ship the clay to their plant, 30 miles north on the Pere Marquette railroad.

This shale is plowed and then taken in wheel scrapers to the switch and dumped into railroad cars through a chute opening in a bridge over the track. The gypsum rock is drilled vertically and blasted with dynamite. The larger blocks thrown out by the blast are broken with sledges and loaded into self dumping mine cars. These cars are hauled to the end of the 320 foot incline by horse or mule, and there attached to a cable which hauls the cars to the top near the mill where they are dumped. The rock is hauled from under the incline track on one horse dump carts a short distance into the mill. A large quantity of rock is piled up at the end of the incline to be used in bad weather and through the winter.

In the earlier history of the quarry, the eleven foot ledge was sorted for different uses, and the parts of the layer were so classified. The upper three feet of the stratum were used for calcined plaster and was called the plaster rock. The next six feet, supposed to be purer in composition and so better adapted to the manufacture of finer plasters and especially for the manufacture of Alabastine wall finish, was called the Alabastine plaster rock; and the lower two or three feet of red gypsum, considered as impure, was used for land plaster, and called the land plaster rock, as indicated in Figure 11 b.

At the present time these different parts are all used for the same purpose and there is no sorting of the rock for ordinary uses. Some of the whiter and more compact blocks are separated and hauled in wagons to the covered store sheds to the southeast of the mill, to dry or season as it is termed, and are then used for the manufacture of Alabastine finish.

The quarry rock is mainly compact, without the saccharoidal or sugary texture, but has dark seams here and there branching irregularly. The seams are caused by dark clay particles and are small in proportion to the white gypsum and do not give a high clay percentage in an average analysis of the rock. The crushed rock is snow white and makes a fine white plaster.

Analysis fails to disclose the cause of the color of the red gypsum as it is as pure as the white rock and shows no higher iron percentage, and when crushed the powder is snow white.

So far there has been but little trouble with water. The small springs in the mines are readily drained away. The level of the floor of the quarry is about 10 feet above the water in the river three-quarters of a mile to the north. The top of the gypsum is approximately level and gives no clue to the dip. As compared with the levels of the Godfrey quarry, the gypsum dips 16 feet to the mile toward the northeast.

The Alabastine Mill.

The mill of the Alabastine company consists of a central brick structure two and three stories high (Pl. VI.) 215 feet long and 55 feet wide with two frame wings 105 and 75 feet long to the east and west. The mill is located about 450 feet north of the quarry. The brick building is used for the grinding and calcining machinery. The frame to the west is the land plaster department, and the west portion of the brick building is the mixing room for the hard plaster (Plasticon). The long frame building to the east is the plaster of Paris department and the ware room.

The engine and boiler house is constructed of brick and located to the south of the center of the main building, and thus removes in part the danger of fire. It is equipped with two 100 H. P. boilers and a 150 H. P. engine. The store room, office, and rock storage shed, are located to the

south of the mill. The buildings on the left of Plate VI, belong to the old plant and the quarry is off to the left of the picture. Plaster creek is back of the mill.

At the center of the large building on the ground floor are located two Butterworth and Lowe jaw crushers right and left of the entrance, with the crackers just below them. North of the crushers in the same room are four runs of four foot buhr stones for grinding the rock for calcined plaster, and one vertical emery stone mill with a capacity equal to two runs of stone used for grinding land plaster.

The coarsely ground rock is carried by elevators from the crackers to storage bins on the second floor, from which it passes by spouts into the hoppers above the buhrs and the emery mill. The flour-gypsum is carried from the stones by screw conveyors to the east room and elevated to bins above the kettles.

The kettle room, also built of brick, is three stories high with the storage bins on the third floor and the kettles extending from the first floor up into the second. The bins extend down into the second story with a long V shaped base which opens into a wooden trough or spout carrying the gypsum into the kettles. There are four ten-foot kettles, each of which will hold nearly ten tons of gypsum. Two of these kettles are connected with the large brick stack and two are connected with separate vapor stacks through which the water passes off. The fuel is added below the kettle on the first floor, and the finished plaster is dumped into fire proof bins on this floor. After cooling for a short time the plaster is taken by long screw conveyor to an elevator at the end which carries the plaster above and over by another conveyor to the west end of the brick building to another set of storage bins. From there it passes down into the mixing rooms where it goes into the Broughton mixers in which a certain amount of retarder is added to form the Plasticon wall plaster, or the plaster is carried to the east ware room and sacked without retarder as plaster of Paris. The plant has a capacity of 135 tons in ten hours.

The Alabastine mixing plant is located on the Grandville road on the bank of Plaster creek and is the original Granger & Ball gypsum mill remodelled and enlarged. It is a two to four story frame building 400 feet long and 200 feet wide, with two frame warehouses 40 by 100 feet attached on the north side. On the ground floor are located the power plant, the packing machinery, and the secret machinery designed for the manufacture of this wall finish. One room is used for the manufacture of paper boxes and another for wrapping and packing. On the second floor are eight runs of 30-inch buhrs for regrinding the product prepared from material received from the other mill. On the third floor are the color mixing appliances designed by the company.

Alabastine finish is plaster of Paris treated to give its proper working qualities and mixed with dry colors. The mixture is reground to the finest powder in the buhrs and packed in barrels and other bulk packages, or in five pound boxes. The capacity of the mixing plant is about ten tons a day and the product is sent to all parts of the country.

The Godfrey Mine and Mill.

The Godfrey mine is located nearly a mile to the east of north of the Alabastine mine and was opened in 1860 and worked until about 1898. The workings are now filled with water up to the level of the top of the upper ledge. The bank above the gypsum shows some variations from the section given for the Alabastine mine. There is practically no gravel covering, but the top as exposed shows (Fig. 12) three feet of shale and then half a foot of limestone separated from a thin eight inch layer of

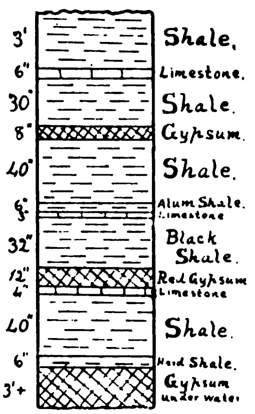


FIG. 12. Section of the Godfrey quarry.

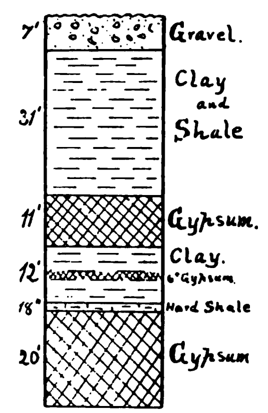


FIG. 13. Section at Taylor brick yard.

gypsum by 30 inches of shale. Below the gypsum come 46 inches of shale, the lower six inches showing an incrustation of alum. This shale rests on another three inch ledge of limestone followed by 32 inches of black shale and a foot of red streaked gypsum and a four inch ledge of limestone. Forty-six inches of shale separate this limestone from the six foot stratum of gypsum at the water level.

A short distance east of this quarry, a section of the Taylor brick yard shows similar conditions to the Alabastine mine with the absence of the six foot gypsum ledge. Here are found in a boring seven feet of gravel and 31 feet of shale and clay used for the manufacture of brick, resting on an 11 foot stratum of gypsum. Following the record down below this gypsum, there are 12 feet of shale and 18 inches of hard rock, probably limestone, and then 20 feet of gypsum.

OLD RED GYPSUM MILL AT GRANDVILLE.

The old work at the Godfrey mine was on the 11 foot ledge which has been removed over a large area extending from the wagon road at the east to the railroad switch to the mill at the west. The rock as far as we can judge from the fragments scattered around the quarry and from the account of the former foreman, Mr. A. J. Wright, was of the same general character as at the Alabastine mill.

A large portion of the old mill is still standing to the northwest of the quarry. It was a two and one-half story frame building equipped with a Godfrey double nipper and cracker for crushing the rock, and with two vertical disintegrators made by Butterworth and Lowe, for the fine

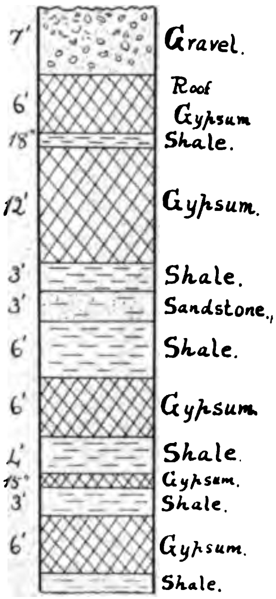


FIG. 14. Section at Powers' shaft.

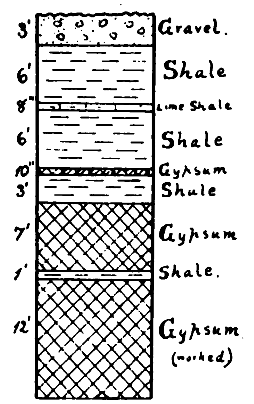


FIG. 15. Section Grand Rapids Plaster Co. mine.

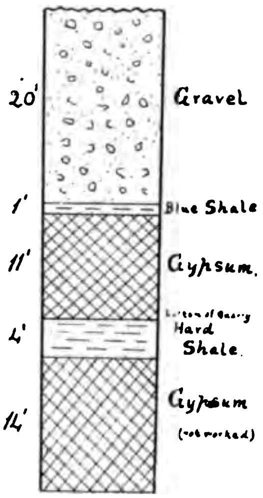


FIG. 16. Section Durr Mine.

crushing and a single run of buhr stones. The mill was run by water power from Plaster creek. A separate building contained two ten foot kettles and the storage bins, but this was destroyed by fire a couple of years ago. A large roofed storage shed was built just south of the quarry and the rock was hauled in dump carts to the mill. The property is now idle and is owned by the Godfrey estate.

Powers Mine and Mill.

This property is located within the city on the west bank of the Grand river about midway between the Pearl and Fulton street bridges. Mr. Wm. T. Powers organized the company and sunk the shaft in 1896. The

mine goes 50 feet below the bed of the river and the framework of the shaft is built up 35 feet more to the floor of the mill. The record of the shaft has been lost and the section represented in Figure 14. is given from the memory of Mr. Powers of the boring made to the roof gypsum and 60 feet below it. The company owns 30 acres of this gypsum land. The upper ledge six to eight feet thick is left for a roof and the mine is worked on a room and pillar system with rooms about 50 feet square and the pillars 20 feet.

It is estimated that by this system about three-fourths of the gypsum can be removed.

The mill was built on the bank above in 1898, and was burned in the

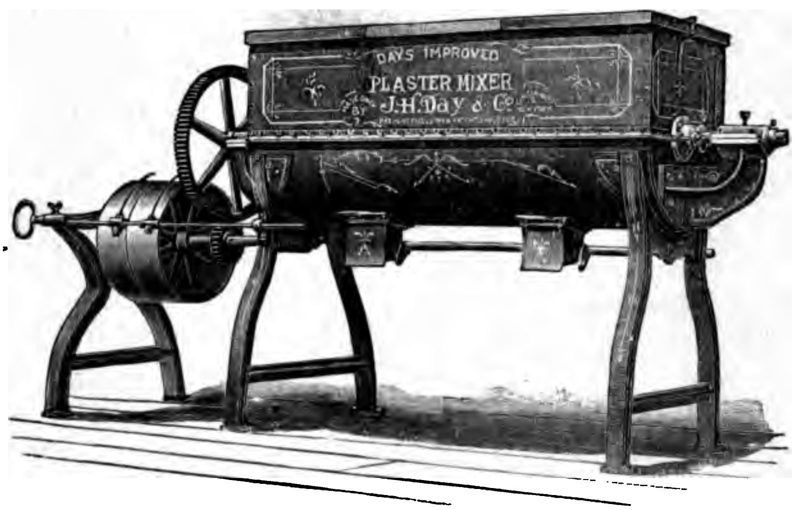


FIG. 17. Day's Lightning Plaster Mixer.

spring of 1903, and the company is known as the Gypsum Products Co. The frame mill was built in an L shape, 130 feet long east and west, and 25 to 50 feet wide with a storage shed built to the east 20 by 20 feet. The wareroom to the west was two stories high and the wider portion was three stories. On the second floor were placed the nipper and cracker and the buhrs below them in two sets, one of 36-inch for ordinary grinding, and a pair of 30-inch buhrs for regrinding. A part of the flour gypsum was carried by conveyors to the west part of the room and sacked for land plaster, and part was elevated to the third story over the kettle placed in the north part of the L extension. The gypsum then passed into the Powers patent kettle which was ten feet in diameter with a new design of flues described in the chapter on Technology, and it was heated by a wood fire. The finished plaster was dumped into fire brick bins and elevated to bins over the Broughton mixer where it was mixed with retarder to form wall plaster.

A special feature of the manufacture at this mill was the granite wall plaster, a sanded mixture ready to be mixed with water and applied to the wall. For this purpose there was on the basement floor a revolving cylinder sand dryer heated with wood fuel. The dried sand and retarder were mixed with the plaster of Paris in a Day's Lightning Plaster Mixer, as shown in Figure 17.

Grand Rapids Plaster Company Mines and Mills. (Plates X, XI, XV.)

On the north side of the river the gypsum is obtained from under the hill by an inclined hillside double entry tunnel. The Grand Rapids Plaster Co. have two double entry mines, one at each of their Eagle mills, known as mine No. 1 and mine No. 2. The main entry runs north and starts into the hill about the top of the 12 foot ledge. The section of the hill for 26 feet above the entry is given in Figure 15, a section which extends from the fence down, in Plate XV. About three feet of gravel are underlaid by 12 feet of shale separated at the center by eight inches of shaly limestone. Below the shale is a ten inch layer of gypsum seen in the photograph above the entry, and separated by three feet of shale from the six to seven foot upper ledge of gypsum. One foot of shale divides the upper from the 12 foot gypsum rock. The hill extends above to the wagon road 40 to 45 feet above the entry, and north of the road the hill rises 100 feet higher though not shown in the photograph.

The seven foot ledge is left for a roof and the 12 foot ledge is quarried for plaster rock. This is worked by a room and pillar system with rooms about 40 feet square and is mined by drilling holes in the upper half of the face of the rock and blasting down with dynamite. This leaves a bench or ledge six feet high which is then drilled vertically and blasted; all of the mining is carried on by this drift and bench system without any undercutting. Pillars of gypsum are left to support the roof, 15 to 20 feet in diameter and between the pillars intermediate timber posts are placed making the mines or caves as they are locally called, perfectly safe. No accidents from caving roof have ever occurred in mine No. 1. In No. 2 there has been no caving of the roof since 1881. At that time the roof covering about five acres fell in one night. The cause was in the placing the pillars too far apart, and the lack of sufficient intermediate posts. Since that time water has been somewhat troublesome in this mine, and about 150,000 gallons are pumped out in a week.

Mine No. 2 is similar to mine No. 1, and now the two are connected, and in all about 45 acres have been worked out. The character of the gypsum is about the same as in the quarries south of the river, showing a compact rock cut by numerous dark seams and with the red rock and the pencil rock at the bottom.

The Eagle mill No. 1 is a short distance south of the mine entry and consists of a group of frame and brick buildings connected by overhead enclosed bridges which are for the conveying of material from one department to the other.

The rock is hauled in mine cars by cables up an incline track to the second floor of the frame machinery building and is crushed in a nipper and cracker, the rock is further crushed to flour in the four runs of buhrs on the same floor as the nipper. The fine gypsum is then elevated to the third floor where the material for land plaster is carried through the overhead bridge to the west to the land plaster warehouse. The material for calcined plaster is carried to the east through another overhead bridge into storage bins in the two story brick calcining building. There are three ten-foot Powers kettles, which are connected with the high brick stack. The calcined plaster is carried to the east room into the large ware room 225 by 40 feet with a bulk capacity of 5,000 barrels, and sacked or placed in barrels as wanted. The engine and boiler house built of brick one story high is at the side of the machinery building. The land plaster warehouse is a one and half story frame to the west.

This mill and the No. 2 mill are located on the L. S. & M. S. R. R. track about two and one-half miles west of the city of Grand Rapids. The Eagle mill No. 2 is located a short distance west of mill No. 1 and is equipped with a Godfrey double nipper and Lowe cracker and the fine grinding is done in three runs of vertical emery stone mills and the regrinding of very fine plaster in two runs of 30-inch buhrs. There are three ten-foot kettles arranged similar to the plan of the No. 1 mill.

The English Mill and Mine.

The English mill of the United States Gypsum Co. is located to the west of the mills last described. It is a three story frame building 40 by 50 feet with a mixing and grinding room to the east 60 by 40 feet. The rock is brought in mine cars from the shaft down a slight incline to the second floor of the mill where the nipper and cracker are located. The broken rock is then elevated to bins above the two runs of buhrs, and one vertical emery stone mill. where the rock is ground to flour which is carried by a screw conveyor and elevated to the third floor above the two ten-foot kettles. The mill is also equipped with three sets of regrinding buhrs for the finer plaster.

The hot calcined plaster is dumped into fire proof bins and then elevated and carried by conveyors to the ware room at the east where it is sacked for the market. This mill was erected in 1900 and has a daily capacity of 150 tons.

The gypsum rock is obtained from under the same hill that is worked

to the east by the Grand Rapids Plaster Co., but it is reached by a vertical shaft on the hillside, 62 feet deep. The shaft is six by eight feet in section, containing double elevators and an independent air shaft. The elevators work alternately and are operated by electricity. The cars carry 2,500 pounds. The drilling in the mines is done by electric drills and the mine is lighted by electricity. The area now worked out is about three acres. This is one of the best equipped mines of gypsum in the country.

The first rock worked in this shaft is a 12-foot ledge, and the six-foot upper ledge is left for the roof. The characters of the rock are similar to those in the other mines of the Grand Rapids area.

§ 2. Grandville Area.

The gypsum quarries of the Grandville area are three-fourths of a mile south of the town. The location is four miles west and five miles south of Grand Rapids, or seven miles by the Pere Marquette railroad. The mines are located in the northwest quarter of section 20 and in the northeast quarter of section 19 in Wyoming township. The old Red mill is located in the corner of section 19 and it is now filled with water and has been abandoned for 20 years.

Across the road in section 20 is the quarry of the White mill, now idle, and to the north in the next field is the quarry of the Durr mill. Both of these quarries have large areas worked out. They are worked by stripping off the surface covering of gravel and so are open quarries.

A section of the Durr mine is given in Figure 16, and shows 20 feet of gravel and one foot of blue shale over the 11-foot ledge of gypsum which rests on a four foot layer of hard shale which forms the bottom of the quarry. Borings show a 14-foot gypsum ledge below this. The lower ledge is not worked as water is a source of trouble at the present level of the quarry and must be kept down by pumps.

The upper gypsum ledge at the Grand Rapids quarries appears to be absent in these quarries, and the upper surface of the 11-foot ledge is very uneven and shows in a marked degree the effects of solution. The gravel cover coming down almost to the gypsum is in marked contrast to the Grand Rapids quarries. The lower part of the 11-foot ledge is of red color and the cone in cone layer reaches six inches in length and is in places free from the red color.

The origin of such cone in cone structure in clay materials has been much discussed, but never satisfactorily explained. Dana regarded such a structure in clay shales as due to the concretions formed under pressure. I have found in western gypsum quarries a layer of satin spar needles on the under surface of the gypsum ledge in the same position as these cones, and the fibres standing vertical as they do in these cones.

The origin of the satin spar in the Kansas gypsum seemed to be due to gypsum waters percolating downward and depositing gypsum in needles which are thus secondary in origin. It is possible that the preceding suggestion of Dana in the cone in cone structure in clay may explain the origin of this gypsum structure; that pressure acting at the same time as the formation of the secondary spar, might cause a consolidation of the needles and form the cone in cone structure as seen in the Michigan quarries. The Michigan gypsum is more compact than the Kansas deposits and so appears to be more firmly consolidated.

The gypsum rock is taken from the Durr quarries in cars and hauled by horses or mules along a T-rail track a little over one-half mile northwest to the mill. A shaft has been excavated near the mill, down through the 32-feet of gravel to the gypsum. This proved a troublesome operation on account of the caving of the gravel, but the shaft has now been firmly timbered, and the mine will be opened and equipped with electricity, and made equal to the English mine at Grand Rapids. When this is completed the quarry will be abandoned.

The Durr Mill. (Plate XIIA.)

The rock from the quarry is stored in two long sheds and hauled from these into the mill on the ground floor where it passes through the nipper and cracker and is hoisted by chain elevators to the second floor. It here passes through four four-foot buhr stones and the rock flour is conveyed and elevated to the bins above the kettles which are three in number, two of these are eight feet in diameter and one is ten feet.

The crushing and calcining machinery are in the three story building at the south end of the long mill. This portion of the mill is connected with the three story mixing plant at the north end, by a ware room, giving a storage capacity of 900 tons.

The calcined plaster is elevated from the bins below the kettles and carried by a long overhead screw conveyor through the ware room to the mixing plant. The plaster of Paris is taken out at various points in the ware room where it is sacked. In the mixing plant the plaster of Paris and retarder are mixed in Broughton mixers.

A special feature of the work at this plant is the manufacture of Adamant wall plaster. The sand for this mixture is dried in three Perfect sand dryers built like a large stove with hopper on the top into which the sand is shoveled and coal is fed in below. The capacity is ten yards a day for each dryer. A cylindrical rotary sand dryer has been installed to take the place of these stoves, and it has a capacity of 60 tons a day.

The dried sand, plaster of Paris, and retarder, are mixed in one of the two Broughton mixers and then sacked in 130 to 140 pound sacks, while

the ordinary plaster, also made in this mill is placed in 100 pound sacks. The patents for Adamant plaster are owned by the United States Gypsum Co., and it is made at a number of their plants.

White Mill. (Plate XIV.)

The White mill, named from the color of the building, is located near the Dürr mill quarry and has now been idle for four years. It is owned by Mr. Dummer of Chicago. The mill though idle is kept in good condition and is under the care of a watchman day and night.

In the center of the building is the power plant with a 150 H. P. Allis engine, steam pump, and small compound engine. The room just south contains the two boilers, and south of the boiler room is the kettle room with four ten-foot kettles with fire brick bins below. The fuel for the kettles and the boilers is added at the east end of this room, and the kettles are so arranged that they can be readily reached and repaired from any side.

The rock was brought from the quarry in large boxes carried on an overhead cable operated by a large drum and engine in the upper part of the building. The cable was supported by two towers, one near the mill and the other on the opposite side of the quarry. The gypsum was dumped in a room to the north of the engine room and was thrown into a Lowe nipper and cracker; then hoisted by an elevator to a half floor above where it passed though four runs of 36-inch buhr stones. The gypsum flour was elevated and carried to the south to bins over the kettles.

The calcined plaster was elevated from the fire proof bins and carried by a screw conveyor to the north of the engine and crushing rooms into the sacking and storage room. This long room is divided into a series of smaller rooms or bins, and from these the sacks or barrels were loaded on the cars on the switch built on the west side of the building.

The Red mill (Plate XIII.) across the wagon road from the White mill is one of the oldest mills standing. It was dismantled a number of years ago and is now passing into rapid decay.

§ 3. Alabaster.

The Alabaster mine and mill are located six miles south of Tawas City and three-fourths of a mile back from Saginaw Bay, and the bottom of the quarry is about 15 feet above the water in the bay. The quarry is located in the northwest corner of section 27 of Alabaster township in Iosco county. A large area has been worked out during the past years of its history, and over a half mile of face is now exposed. Probably no gypsum quarry in the United States turns out as much rock in a year as this one which has an annual output of a hundred thousand tons. The

workings show a solid ledge of gypsum 18 to 22 feet in depth covered toward the bay by five to eight feet of clay with gravel through it, and toward the west by 12 to 16 feet of stiff boulder clay which is stripped by means of a steam shovel with a capacity of 840 cubic yards a day. The clay is loaded into small dirt cars and hauled by a small steam engine and dumped into the abandoned parts of the quarry.

The rock is drilled to a depth of 16 feet and blasted with dynamite, and the larger masses from the blast are broken with sledges and loaded into small ballast cars and hauled by a second steam engine to the mill or to the wharf.

The rock is compact and more or less streaked or banded with darker streaks composed of clay and dark gypsum. Selected masses are snow white without a trace of dark color. The lower one and one-half feet of the ledge are red in color and near the bottom are composed of nodules of reddish or white gypsum surrounded by impure clay gypsum. On weathering the nodules separate and the dark portion crumbles. This portion of the ledge is thrown to one side and is not used at the mill. The floor of the gypsum is a fine grained, bluish sandstone.

It is stated that an old shaft was put down in the quarry 65 feet below the level of the basal rock and passed through a total of 25 feet of gypsum. According to Mr. Gregory, in the earlier history of this quarry, there were two layers of this gypsum separated by a layer of hard fossiliferous limestone and a small stratum of shale, but upon working into the deposit the shale and limestone have entirely disappeared. The mine and mill are connected by a five mile switch with the Detroit and Mackinac R. R.

The mill is built about half way between the quarry and the bay. This consists of a group of buildings, the main one being 40 by 52 feet and contains the grinding machinery and the three ten-foot kettles built with the four interior flues on a line. An extension has been made to the machinery building which is 24 by 64 feet and reaches out to the railroad track. The upper part of this building is the storage room for the bulk plaster and this is sacked below and loaded directly on the cars.

A shed 200 by 28 feet has been erected to store sacks and the finished product, with an extension 40 by 100 feet which adds 1,500 tons storage capacity. The rock shed is 40 by 200 feet and will hold 3,500 tons of rock stored for winter use. The two story carpenter shop was used at the old mill for the manufacture of barrels and nearly 30,000 of these were used every year, no material being sent out in sacks. In the new mill, built in 1892, sacks have been used, and only about 7,000 barrels are needed a year. These are made in the carpenter shop which is also used to store parts of machinery. lumber, and the like.

In addition to the mill buildings, the company has erected 40 houses to

THE WHITE MILL AS SEEN FROM THE QUARRY, GRANDVILLE.

accommodate the workmen, a two story hotel 70 by 80 feet, and an office building and store 60 by 60 feet. The rock which is shipped by water is hauled in cars by the small engine out on the 600 foot pier and loaded directly into sailing vessels holding 450 to 700 tons, or it is stored in a two story warehouse 40 by 100 feet, built on the end of the pier. The rock is hauled up an incline to the second story and loaded through iron chutes. The finished product is hauled into the lower part of the warehouse and loaded by hand trucks on the boats.

In the Alabaster mill grinding machinery is on the first floor and consists of a Lowe nipper not used at the present time, and a large cracker into which the rock is now thrown as it comes from the quarry. The gypsum is then ground in a Stedman disintegrator or in three runs of buhr stones. Two sets of 36-inch buhrs are used for regrinding the rock flour for superfine plaster used especially in the plate glass works. The mill is equipped with one Raymond machine, formerly used for grinding this extra fine plaster, but it has been out of use for some time. The gypsum flour is elevated in double bucket elevators and carried in screw conveyors to bins over the kettles. The calcined plaster is elevated and conveyed to the store houses by long conveyors one of which is 150 feet long. In the ordinary plaster the retarder is added in two Broughton mixers. Power is furnished by a 150 H. P. engine and the capacity of the mill is 200 tons in 24 hours.

Other Gypsum Deposits in the Alabaster District.

West of Alabaster Point, according to Winchell,[1] the gypsum formation can be found for a distance of 30 miles near the surface on all the head branches of the Au Gres river.

"In township 21, range 5, section 12, is another similar exposure of rich gypsum deposits, and numerous smaller deposits are noticed in the beds of creeks between that locality and the lake."

Prof. W. M. Gregory[2] has made a very careful study of the geology of this region, and his account of the distribution of the gypsum is given in § 6 of Chapter V.

"The outcrops of this formation have a limited area in this region and no evidence of gypsum in the Grand Rapids group outcropping has been found north of the line connecting Tawas City and West Branch and south of a line connecting West Branch and Au Gres. Gypsum is found in the deep wells of the Saginaw valley, but the above statement refers

[1]Geol. Survey of Mich., Vol. III. p. 107; 1876
[2]Geol. Survey of Mich., Annual report for 1901, pp. 16-18.

to a region in which a search might reveal the rock in suitable condition for practical working.

Judge Sharp, of West Branch, is the authority for the statement that three and one-half miles east of West Branch on the Rifle river is an outcrop of gypsum, which several years ago caused much excitement for its size and purity. No careful exploration of this bed has been made and at present it is undeveloped."

CHAPTER VIII.

TECHNOLOGY OF GYPSUM AND GYPSUM PLASTERS.

§ 1. General Process of Manufacture.

Gypsum rock as described in the chapter of Chemistry is a mineral composed of sulphate of lime and water ($CaSO_4 . 2H_2O$). When this rock is heated to the proper temperature it loses part of the water and is then

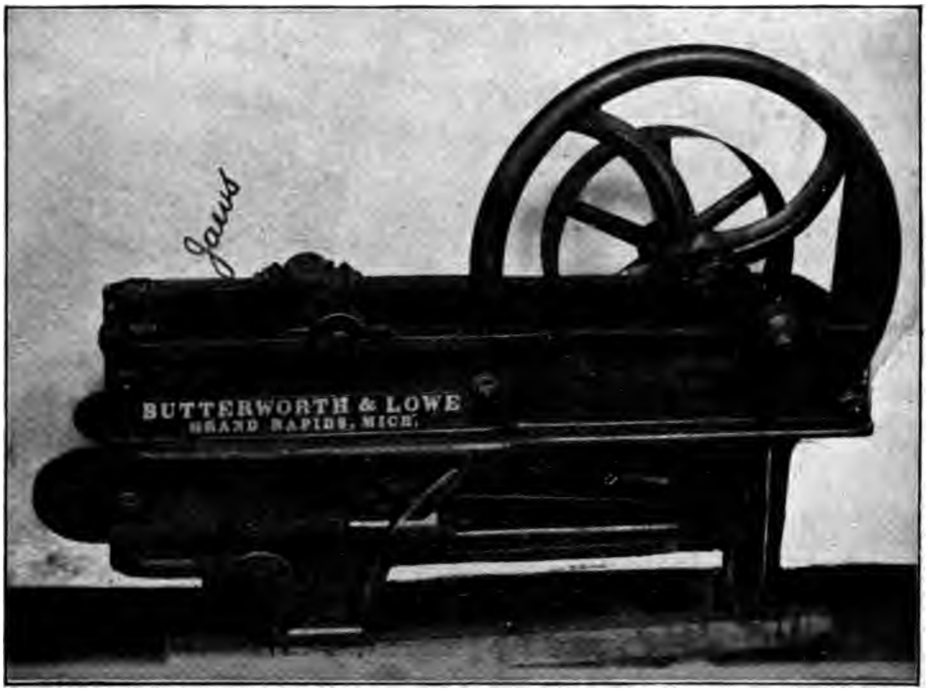


FIG. 18. Jaw Crusher for Crushing Gypsum.

known as plaster of Paris $(CaSO_4)_2 . H_2O$, a compound capable of taking up water when it is added to it, forming the set plaster.

The essential parts of the process of manufacture are the proper grinding and proper burning, and it is the aim of this chapter to present the methods used in reaching these results.

In a number of the foreign countries, especially in France and in some

of the English mills described in an earlier chapter, the gypsum rock is burned and then reduced to powder. The practice in the Michigan mills and practically all the mills of this country, is to crush the rock and burn the rock flour in kettles or cylinders.

Most of the material in the United States is prepared in mills and kettles of the same general type; but there are some variations regarded by many of the plaster men as improvements, and there have been some attempts at improvement which have proved to be failures.

§ 2. Crushing of the Rock.

In the typical Michigan mill the gypsum is treated according to the following plan: On the second floor of the mill are placed the jaw crusher, the nipper and the cracker. The nipper as shown in Figure 18 has a corrugated face plate of chilled iron forming the end of the machine, and a swinging apron of the same pattern which forms a V shaped box. The

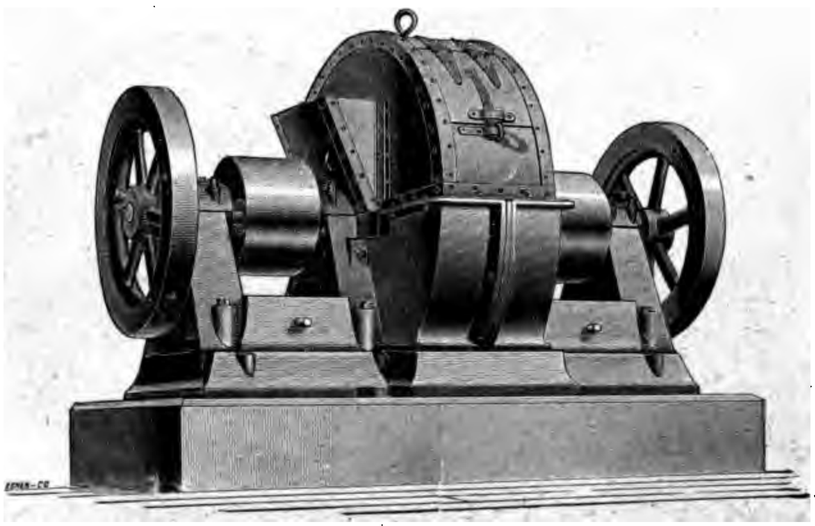


FIG. 19. Gypsum Disintegrator, made at Aurora, Indiana (closed).

apron is driven against the fixed plate by an arm which moves with an eccentric motion on the shaft, so as to give a backward and forward movement, and the shaft is moved by steam or water power. Such a machine weighs about 6,000 pounds and has a capacity of seven to eleven tons per hour. Mr. Godfrey invented a double swinging apron jaw crusher which gave an increased capacity, but it is only used in two mills in the State.

Blocks of about 50 pounds weight are thrown into the jaws of these machines and are crushed into pieces about the size of a man's hand. The small masses drop from the crusher into the cracker set in the floor just under the crusher. This machine has a conical corrugated shell in which revolves a shaft with a corrugated iron shoe, working like a coffee mill.

Three sizes of this type of machine are made, with a capacity of three, seven, and twelve tons per hour, the usual size is the medium one which has a weight of 3,300 pounds. The cracker was originally patterned after the old corn mills which ground the cob and corn in one mass.

The gypsum is further crushed in the cracker into fragments of the size of small gravel, which fall into the buckets of a chain elevator whereby they are raised to storage bins on the floor above. From this bin the gypsum particles pass down by gravity through spouts into ordinary buhr mills or emery stone mills, where they are ground into flour.

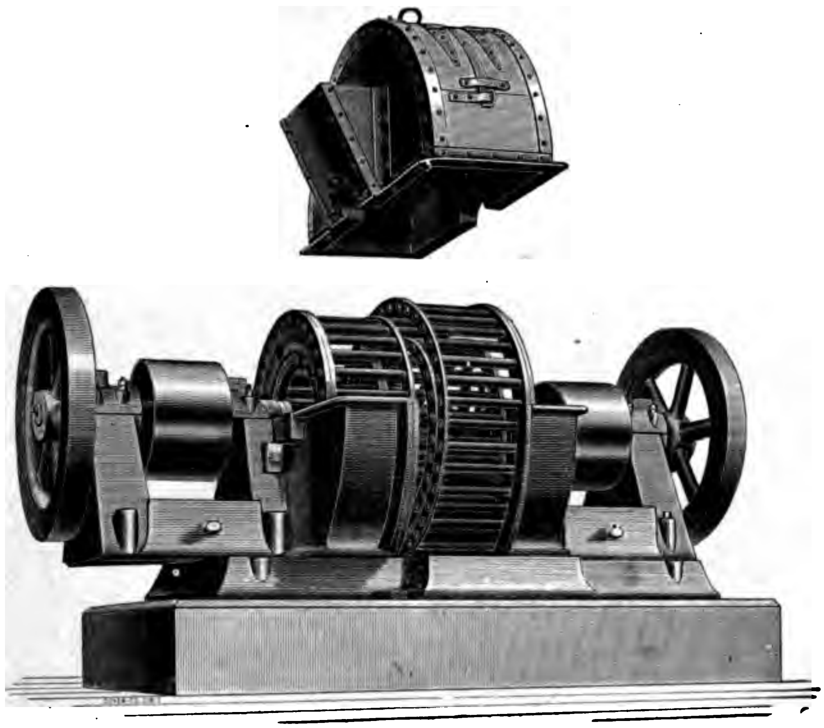


FIG. 20. Gypsum Disintegrator, same as Fig. 19 (open).

The two buhr stones are arranged as in a flour mill usually with upper runners, and ranging in diameter from 32 to 42 inches. Most of the buhrs in Michigan are French stones obtained from old flour mills. They are cut in radiating furrows and when ground smooth by the friction of the gypsum particles must be redressed. This operation requires skilled labor and usually one man is employed at the mill for this purpose. It is also necessary to have an extra set of buhr stones as in a large mill one set is out of use most of the time.

To increase the capacity and avoid the expense of dressing the buhr stones, other types of machines have been invented, and used to some extent in the Michigan mills. One of these is the lime disintegrator, in-

vented and made by the Stedman Foundry and Machine Works of Aurora, Ind. One of these disintegrators is used in the Alabaster mill and in the Chicago mill of the U. S. Gypsum Co. This machine as shown in Figures 19 and 20, consists of two cages with short cross bars. These cages travel at high speed in opposite directions. In the Alabaster mill, the disintegrator runs at a speed of 800 revolutions per minute. The gypsum is carried by a spout into a hopper at the side and passes to the center of the cages where the centrifugal force carries the particles between the bars of the cage. These bars passing in opposite directions beat the rock into powder by the impact against the bars, and by the striking of the gypsum particles against each other. There is no danger of choking or clogging of the machine and the action is rapid. The capacity of a 50-inch disintegrator is 60 to 75 tons in ten hours.

Another type of machine for crushing the gypsum gravel from the cracker to flour is the Sturdevant emery-stone mill, made by the Sturdevant Co., of Boston.

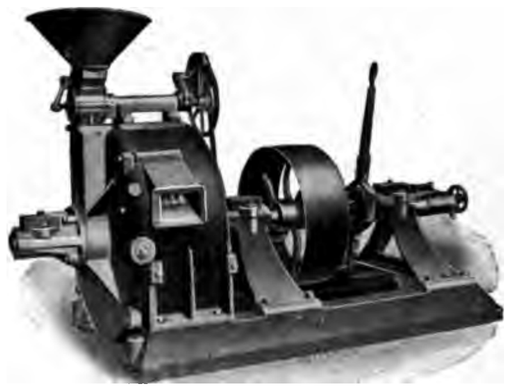


FIG. 21. Sturdevant Emery Mill.

This mill, as shown in Figure 21, is made after the pattern of buhr stones set to run in a vertical direction. Its grinding surface is composed of large blocks of emery stone as it comes from the mine, set in a metal frame. These blocks are so arranged that the grain of the emery runs at right angles to the face of the stone, giving the maximum cutting power. It is made of large pieces fitted as closely as possible and the crevices filled in with smaller emery. A special composition metal is then poured in from the back making a solid casting, and the whole is strengthened by steel bands. The center of the mill stone (Figure 22) is made of buhr stone in order to produce a more even wear on the surface, as the speed and consequent wear is greater toward the border than near the center. The bed stone is bolted to the mill frame and does not have to be removed till the stone wears out.

These emery mills are said to reduce the cost of grinding nearly one-

half, and can be dressed in much shorter time than ordinary mill stones, and they can be run at much higher speed. Such mills are made in sizes from 30 to 54 inches in diameter. The 30 inch emery stone mill weighs 3,500 pounds and will grind one to four tons per hour, requiring from 18 to 20 H. P.

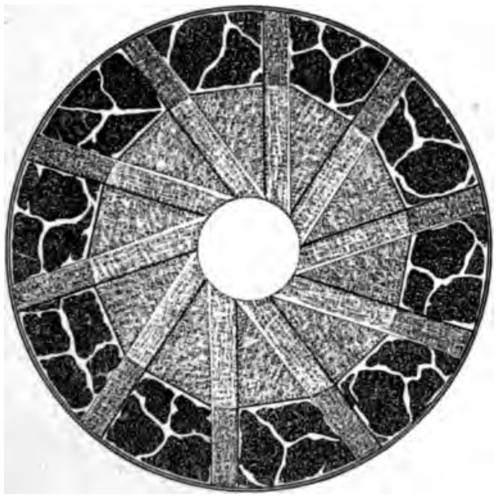


FIG. 22. Sturdevant Emery Mill Stone.

§ 3. Calcining.

After the gypsum is ground to flour by some of the methods described above, it passes into a screw conveyor, and is elevated directly to the floor above and then conveyed into storage bins located over the kettles.

The ground gypsum flour is allowed to run by gravity from the storage bin into the calcining kettles. All of the kettles in Michigan are constructed after the same general plan, a plan introduced from New York by Mr. Godfrey. The kettles are constructed in the form of a hollow cylinder made of boiler steel three-eighths of an inch thick and are about as deep as wide, ranging from eight to ten feet, and the latter is the usual size in Michigan. The cylinder sets on an iron ring and on this ring inside of the kettle is placed the convex bottom made of such a mixture of

FIG 23. Day Fiber Picker.

irons that it will have a low shrinkage, even as low as 3-64 of an inch in passing from the molten to the cold stage. This bottom is made convex upward and about 5/8 of an inch in thickness fitted with small rings at the top which enable one to fasten chain and tackle to it and so place the

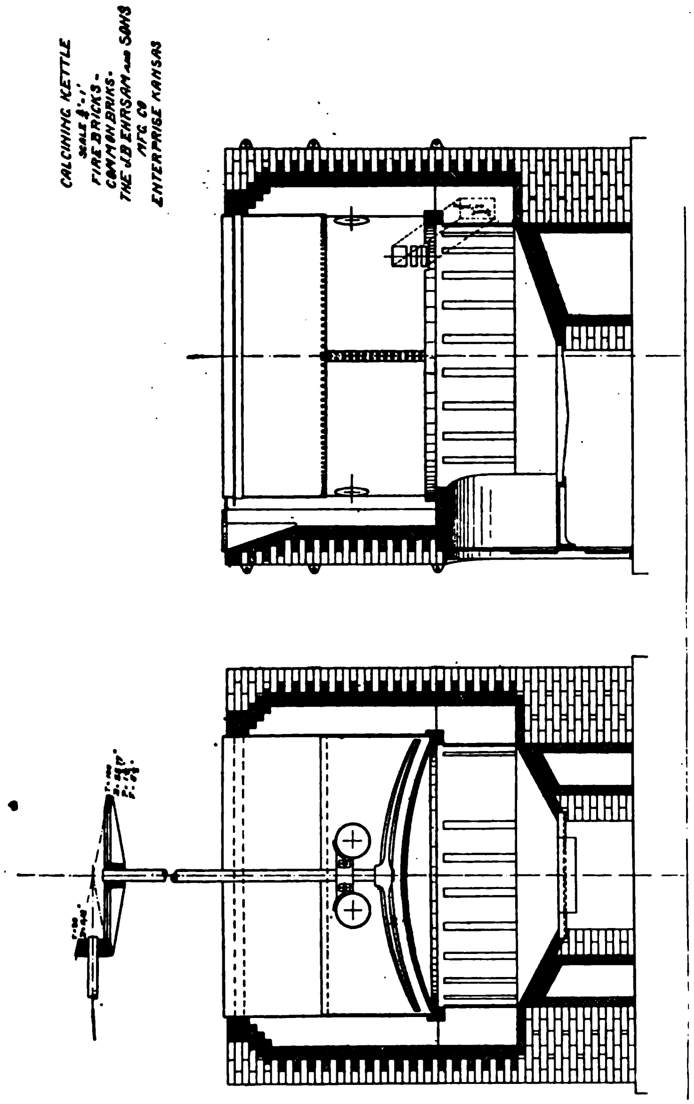


FIG. 24. Ehrsam Calcining Kettle.

bottom in the kettle where it is firmly fastened to the cylinder with moulder's cement. Sectional kettle bottoms have been invented and are made by the Des Moines Mfg. and Supply Co. On account of the uneven contraction and expansion in different parts of the kettle resulting in the warping or buckling of the plates, it is claimed at the Michigan mills that

ENTRANCE TO GYPSUM MINES.

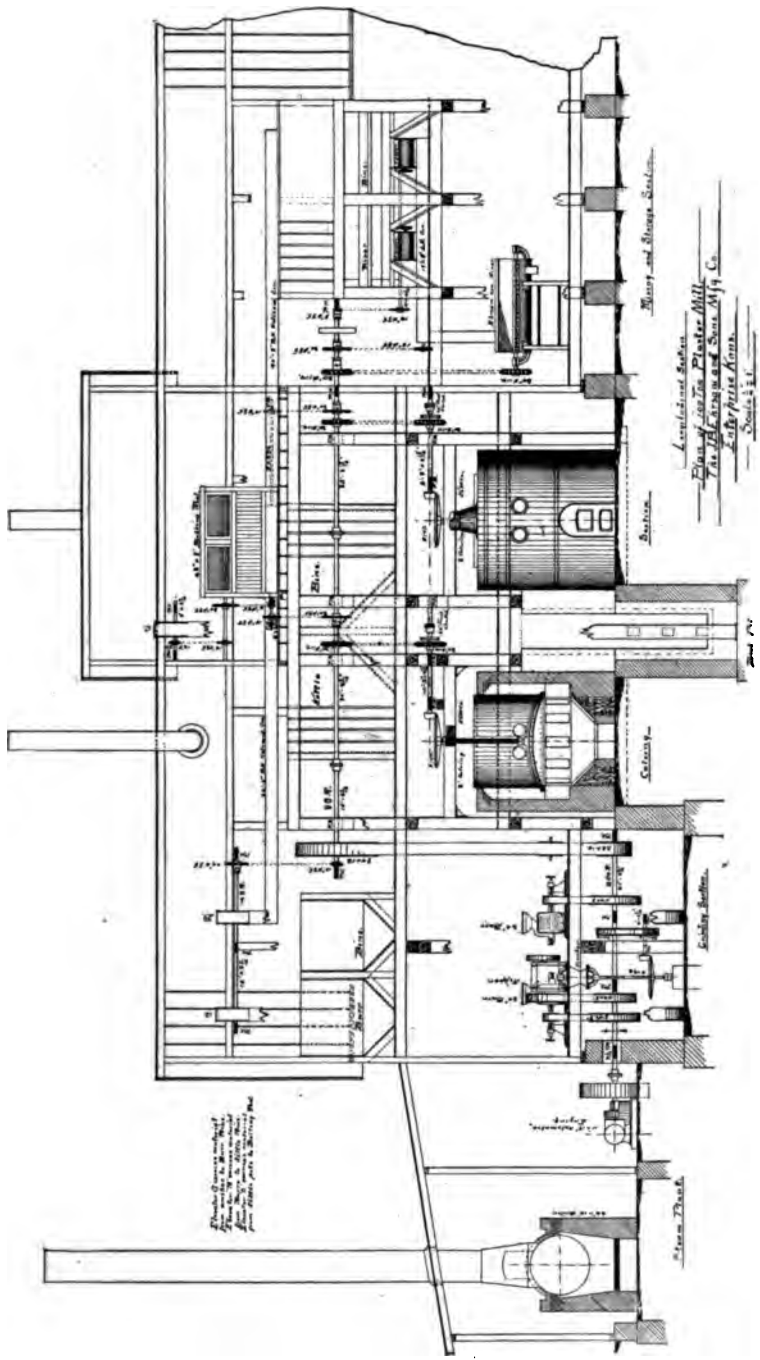


FIG. 25. General plan of Plaster Mill, showing Calcining Kilns and other machinery in place.

it is very difficult to fit in the single pieces. This type of kettle bottom is used in a number of Iowa and Kansas mills and they are said to be satisfactory in those mills. They are made in six radial sections and one center piece. A ten foot kettle bottom weighs approximately 4,400 pounds.

The kettle is set like a boiler upon a brick base and surrounded by a wall of brick 12½ to 17 inches thick separated from the kettle by seven to ten inches of air space. The grate bars were formerly placed four feet and now seven feet below the kettle bottom. The fire place is about four and

FIG. 26. Four Flue Gypsum Calcining Kettle.

one-half by three feet, though in one Michigan mill the grate is six by four feet. It requires about 3,300 fire brick and 19,000 common brick to set such a kettle. Figure 24 shows the plan of a four-flue kettle set in position.

Figure 25 shows the general plan of a plaster mill with kettles, elevators, storage bins, etc.

In the old style of kettles no flues passed through the kettle, but in the kettles now in use, there are two to four flues passing through the kettle about the center. In the Michigan kettle four flues are used, two above the center and two below, as shown in Figure 26. In the Butterworth &

Lowe kettle there is a division between the two sets so that the heat passes up in the open space on one side and through the lower two flues, then back through the other set and out through the chimney flue. In the Iowa type of kettle and in a few of the Michigan kettles the four flues are on a line. The kettle flues have been gradually increased in diameter from 7 inches to 16, and are 36½ inches apart on the horizontal line in a ten-foot kettle, and are ten inches apart up and down.

The experiment tried on the amount of fuel required to calcine plaster in two kettles, one with the four flues on a horizontal line, and one with the flues arranged two above and two below, appears to show an advantage in favor of the latter arrangement. The results of this experiment are given in the following table kindly furnished by Mr. Lowe of Grand Rapids.

The kettles were properly set and with good draft. The gypsum was ground so that 85 per cent would pass through a 40 mesh sieve. The experiment was watched on the second batch after the kettle had been fully heated. The material was discharged after the second settling and was fully calcined, and the weight of plaster was eight and one-fourth tons, with a water percentage of five and one-half.

Type of four-flue kettle.	Condition of rock.	Pounds of bitum. coal.	Time in hours.	H. P. required.
Direct, flues 0000	Green	1,030	3 7-12	12
Return, flues $\frac{00}{00}$	"	880	3 8-12	13
Direct, flues 0000	Dry	850	2 10-12	10½
Return, flues $\frac{00}{00}$	"	730	2 11-12	11½

The material in the second experiment was discharged at the end of the first settling and total weight of plaster was eight and one-half tons, with a water percentage of eight. In the direct arrangement the heat passes through flues and out. In the return the heat passes through two flues then back through other two and out.

Type of four-flue kettle.	Condition of rock.	Pounds of bitum. coal.	Time in hours.	H. P. required.
Direct, flues 0000	Green	765	2 9 12	12
Return, flues $\frac{00}{00}$	"	660	2 10-12	13
Direct, flues 0000	Dry	600	2 1-12	10½
Return, flues $\frac{00}{00}$	"	580	2 2-12	11½

These kettle flues are arranged with openings in the brick work. closed by doors which can soon be opened and the flues cleaned from time to time.

The gypsum flour is constantly stirred on the bottom of the kettle by a convex revolving arm with a length equal to the diameter of the kettle, and with small cross pieces projecting below and set at an angle so as to reach all portions of the bottom. The arm is fastened to a four inch vertical shaft which is driven by a five foot horizontal cog crown wheel, set in motion by a one foot vertical pinion wheel attached to the power shaft. Above and below the flues two stirring rods are also attached to the vertical shaft. It requires 10 to 25 H. P. to run this stirrer, and sometimes if the plaster is run too fast into the kettle, the resistance is sufficient to break the teeth or cogs from the pinion wheel. The stirrer makes about 15 revolutions per minute. A ten-foot kettle will calcine three and one-fourth tons of ground gypsum per hour, and a two kettle mill with the necessary machinery for taking care of the rock will require 85 H. P. when emery mills are installed. A complete ten-foot kettle with bottom and vapor stacks weighs 19,000 pounds. The kettle is covered with a sheet iron cover, with an opening or door which can be shifted so as to see the interior.

In the Powers patent kettle 40 three-inch flues are built around the circumference of the inside of the kettle, each forming a segment of an oval. This arrangement gives more clear space in the kettle and is claimed to make a considerable saving in fuel. In the Powers mill at Grand Rapids, ten tons of plaster can be made in a ten-foot kettle in one batch.

In an hour after the gypsum kettles are filled the temperature reaches 230° F., and the mass is seen to be boiling vigorously, as the water is driven off and out through the vapor stacks above. When the temperature increases to 270° F. (132° C.) the gypsum settles down solid leaving 16 inches or more of vacant space at the top. and the steam almost ceases to rise. At 280° or 290° F. (138° to 143° C.) the mass comes up again, often throwing a part of the material over the top of the kettle. When the temperature of 350° to 370° F. is reached, the plaster is readily withdrawn through a gate near the bottom controlled by a lever above, into a fire brick bin on the ground, and the kettle is then refilled.

In some mills these temperatures are carefully watched and a dial thermometer with long rod, or a thermometer attached to a long stick, is thrust through the door at the top of the kettle and the temperature read. Gypsum plaster is a good non-conductor of heat, and it clings to the cooler thermometer bulb or tube placed in the mass, and so causes the instrument to record a lower temperature.

In most of the Michigan plants the expert calciners who have spent years watching the plaster, learn to tell the stages of the burning by the appearance of the boiling plaster or by the amount of steam passing out

through the vapor stacks, and even by the creaking sound of the machinery caused by the settling down of the plaster throwing more strain on the cogs, and when the strain is relieved by the final boiling of the mass, the creaking sound ceases. Some calciners with little experience attempt to calcine plaster without a thermometer, and then are apt to work by guess, making a plaster of variable quality, but such workers are few in the Michigan mills, especially at the present time when competition among the mills requires the best plaster that can be manufactured.

In the earlier days of the plaster industry the plaster was withdrawn at the end of the first settling, and in recent time this method has been followed to save fuel and increase capacity, but such plasters are of lower strength and are often rejected by the plasterers.

The whole process of calcining, after the kettles are heated to the proper temperature, requires two and one-half to three hours, and there is a loss in weight of 12 to 14 per cent due to the loss of water. Three kettles are burned in a day. requiring about 1,200 pounds of coal in dry rock, and as high as a ton of coal in moist rock. Where wood is used it requires one-fourth cord of slab wood, costing $1.90 a cord, to burn ten tons of plaster. The favorite coal used is the Ohio and Indiana block.

The great objection to the present kettle system of calcining is the great amount of heat required to calcine the mass of cold gypsum thrown into a kettle with thick bottom, and a considerable amount of heat is wasted by radiation from the kettle. This has been lessened by the arrangement of flues in the interior of the kettle. Another objection is the large horse power required to stir this mass of gypsum and so keep it from overburning on the bottom. The great heat at that place tends to warp and burn out the kettle bottoms which are heavy and expensive to replace.

In the early history of the Michigan industry attempts were made to avoid these troubles by using rotating cylinders as described in the historical chapter. Various forms of cylinders have been invented, but with one exception, to be described, these have attracted little attention. Butterworth and Lowe purchased one of these patents and improved it, but have now ceased to manufacture them.

The objection given to the cylinder method of calcining is the difficulty of determining when the plaster is properly calcined. The expert calciner cannot see plaster boiling in the enclosed cylinder, and all of his tests of the appearance of the boiling mass, the rising steam, the creaking machinery, have disappeared or are so modified that he can no longer recognize them. He is at a loss to determine the time to draw the finished product. If he depends on a time limit of a certain number of hours or parts of an hour, the rock may vary in amount of contained moisture and so have to be drawn at different times. This might be determined by the thermometer. but this method of determining temperatures does not appeal to men skilled in kettle methods. These objections have prevented

the rotating cylinders from being adopted in any of the Michigan mills, and the method is generally condemned in this State.

Plaster machinery has improved very slowly in comparison with ma-

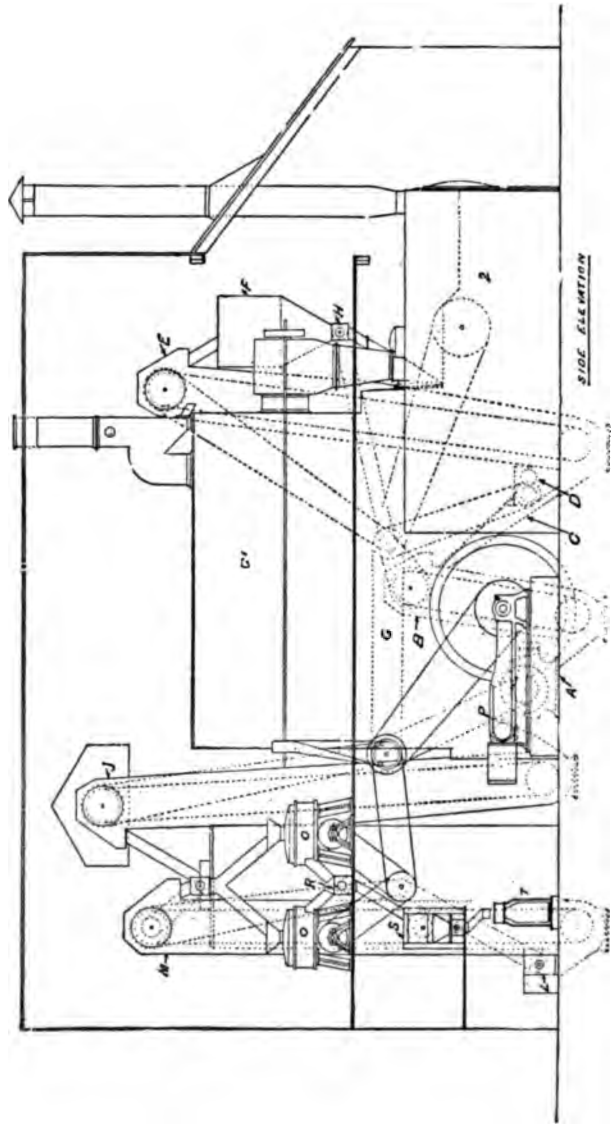


FIG. 27. Cummer Continuous Calcining Kettle (sectional view).

chinery in other lines of rock product manufacture, and it is hoped that new and better methods will be invented and that prejudice alone will not stand in the way of their adoption.

§ 4. Cummer Rotary Calciner.

A year or more ago the F. D. Cummer Co., of Cleveland, Ohio, invented

a rotary cylinder for calcining plaster, and has installed these in several plants. At the present time this is the only company in this country which is meeting with any success in this line of gypsum machinery. From the experience in the Portland Cement mills, this method would seem to be the logical method of calcining such plaster, it it could be

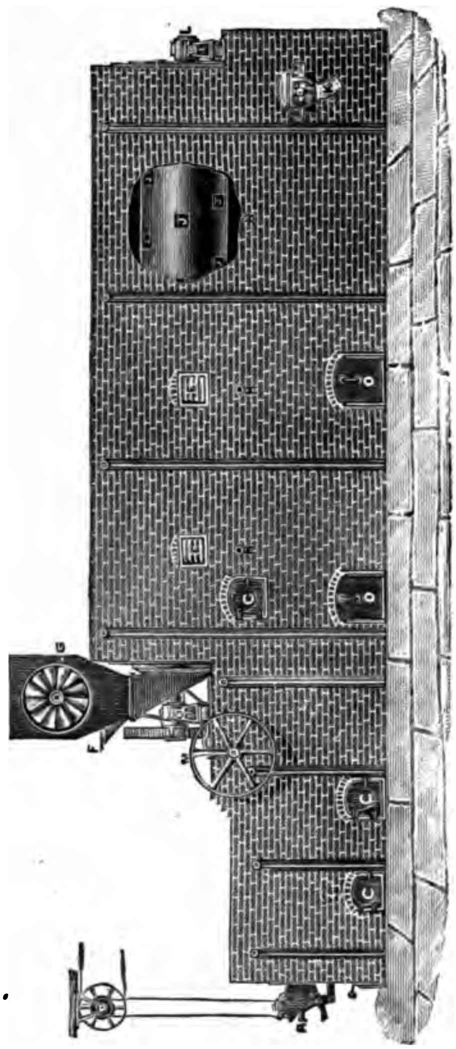


FIG. 28. Cummer Continuous Calcining Kettle (outer view).

proved that the plaster could be made of good and uniform quality, and this the Cummer Co. claim to be doing, and are willing to guarantee.

The Lycoming Calcining Co. of Williamsport, Pa., is using the Cummer process in a plant of a capacity of 50 tons of plaster in 11 hours, using slack coal as fuel, and they claim there is a large saving in horse power

and labor over the kettle method, and that the plaster is of a high strength and is satisfactory to the trade.

The gypsum blocks are crushed in a jaw crusher, A, (Figure 27) and by rolls, D, so as to pass through a one inch ring screen, C, and the material is then fed into the rotary calciner, G, from the storage bin, F. This cylinder is 27 feet long and four feet in diameter set at an incline and slowly revolved. It has a large number of hooded openings, J, (Figure 28) so arranged that heated air and gases are drawn in from the chamber around the cylinder. The material is constantly raised and dropped in the cylinder by means of the lifting blades. The heated air traverses the

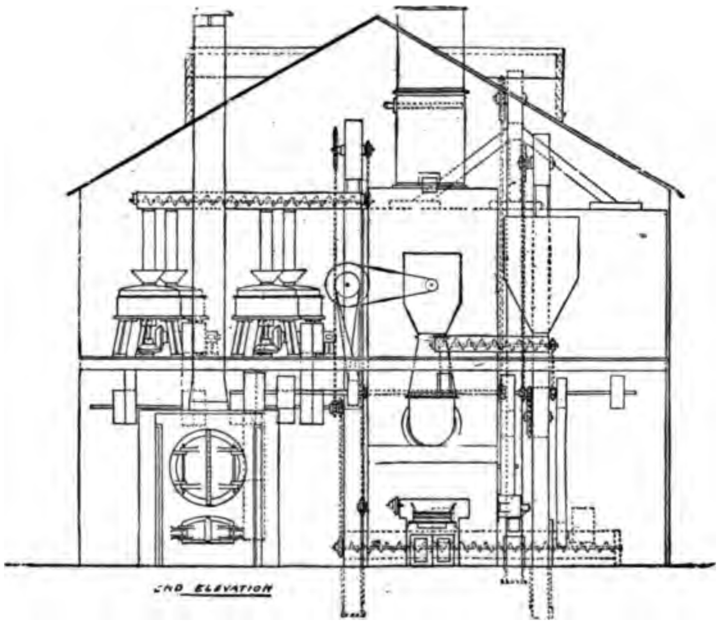


FIG 29. Cummer Continuous Calcining Kettle (end elevation)

cylinder in the opposite direction of the material. In Figure 28, A, is the stoker front, C, C, are cleaning doors, K, is the discharge for the calcined product, H, H, are holes in the masonry in which the pyrometers for measuring the temperature may be placed, M. is the driving pulley, F, is the hopper, and G, is a fan for controlling the flow of the gases and heated air.

The material delivered from the rotary calciner is steaming and heated to from 350° to 400° F. Elevators carry the plaster to the three specially constructed brick calcining bins, 30 feet long, six feet wide, and 29 feet deep, where the resident heat of the plaster completes the process of calcination and the material is cooled in about 36 hours. The cooled plaster rock is mechanically discharged into the elevator, M, (Figure 27)

which carries it into small bins placed over the grinding mills, O. From these mills the conveyor delivers the pulverized material to the screen, S. The finished product is sacked at T. The end elevation of a Cummer mill is shown in Figure 29.

In the kettle method, the calcined plaster after remaining in the fire proof bins a time to cool is taken by conveyors and elevators to an upper floor and passed over screens. The screens by means of double eccentrics have a shaking motion and are usually about three and one-half by four and one-half feet in size covered with wire cloth sieve, and are set at a sloping angle. The fine plaster passes through and the coarse particles or tailings are conveyed back to the buhrs for regrinding. In the western United States plaster mills, the sieves are 30 to 35 meshes to the square inch. In Michigan and Ohio they are usually 35 to 45 meshes to the square inch, and in New York 40 to 55 mesh sieves are generally used.

In some plaster mills the plaster is screened by passing into a horizontal cylindrical reel 40 inches in diameter and 10 feet long, slanting downward three-eighths of an inch to the foot, and made of 40 mesh wire cloth. The screenings in both of these methods average about one per cent of the total.

The screened plaster is conveyed into bins on the second floor of the mixing room where it may be run into sacks of 100 pounds weight or into 265 pound barrels, and sold for plaster of Paris, or as it is called in Michigan, stucco. This word stucco is used in the United States in a variety of ways. In Kansas it usually refers to plaster made from earthy gypsum (gypsite). In other sections, and this is the correct use of the term, it refers to a plaster of Paris with glue or some retarder added to it to delay the time of setting.

The retarder was formerly added to the plaster in the kettle a short time before drawing the product, but this method produced uneven results. It is now added in correct proportion in a mixing machine of the type of the Broughton mixer shown in Figure 30. This machine is made of iron or steel with a receiving hopper below constructed of wood, and the machine is adapted for continuous operation.

While one charge is being sacked, another is being mixed, and the third is filling the hopper above, which holds 1,000 to 1,400 pounds. The capacity of a five bag machine is 300 to 400 barrels per day of ten hours, requiring 8 to 12 H. P., and with a weight of 4,750 pounds.

The finished plaster some years ago was always placed in barrels with a weight of 300 pounds. At the present time some of the material is placed in barrels of 265 pounds weight. but most of the plaster is sold in sacks of 100 pounds weight. These sacks cost about eight cents each in wholesale lots and are charged against the customers who receive a rebate of the amount paid when the sacks are returned.

§ 5. Progress in Technology of Gypsum Plaster.

In the early days of the Michigan plaster industry, the calcining was done in cauldron kettles holding a few barrels and stirred by hand. A little later several of these kettles were set in an arch similar to the plan now used in the kettle block system of making salt from brines. This crude method was improved by Mr. Freeman Godfrey, by the construction of a six foot calcining kettle with a stirring appliance moved by water power. These kettles were increased to eight feet and then to ten feet in diameter, and one company has even considered a 12 foot kettle. Experience seems to show that in economy of fuel and power, the most profitable kettle is the ten foot size, and this has now come to be the standard size in gypsum mills.

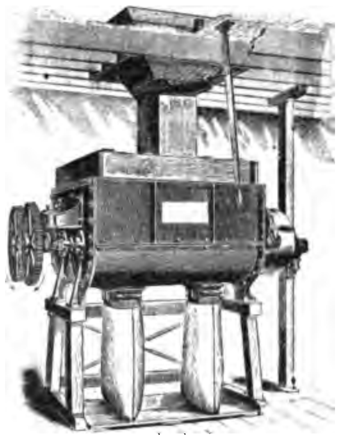


FIG. 30. Broughton Plaster Mixer.

The interior flue system enabled the plaster to be calcined with less fuel than without, and in many of the western mills two flues are considered as good as four and give greater capacity to the kettle. If no partition is added in the air space around the kettle to separate the two sets of flues, there seems to be no advantage in the extra two flues. The Iowa plan of four flues on a horizontal line seems to require more fuel than in the arrangement of two above and two below, as indicated in the table given under that section of this chapter.

The size of the flues has been increased from 5 to 16 inches in diameter, and this is regarded as the maximum size for economical working of plaster, though there is some difference of opinion on this point. The size of the grate has been increased and most plaster men agree that a fire place four and one-half by three feet is the most economical.

Progress, then, in calcining plaster in Michigan in the past 30 years

has been in enlarging the capacity of the kettle and in the saving of fuel. In the early days when wood was abundant and was the only fuel used in this work, there was no incentive to improvements which would save fuel. In the present day of active competition and occasional cutting of prices, it is important to save expense at every turn and to improve the product as much as possible.

The improvement in product has been in the more complete removal of water in the gypsum rock. The old plasters were removed at the end of the first settling as fully calcined. Such plaster would scarcely sell today at any price in competition with plaster removed after the second settling.

Another improvement has been along the line of fine grinding and increase in capacity of grinding machinery. Some mills today are turning out a plaster so finely ground that there is scarcely a trace of grit in the mass. The Stedman disintegrator, and the Sturdevant emery mill give a greater capacity for the power required and cost less for repairs than the old style buhr mill, but many plaster manufacturers claim the resulting plaster is not so fine in grain. With the use of these machines, when a very fine ground plaster is needed for any special kind of work it may be reground in a small buhr mill. For ordinary wall plaster work it is very doubtful whether such fine plasters are any better than the coarser grades.

This progress in improvement in grinding machinery has only come in the last few years and is so new to many plaster men that they are not ready to adopt them. No machine appears to the plaster men so valuable for crushing the coarse rock as the old nipper and coffee mill cracker used for over 30 years. In some of the New York mills Blake crushers have displaced the old type of crushers, but the number is as yet small.

It is but natural that appliances used for so long a period of time, which make a plaster of high strength and uniform quality, and by which in past years the owners of mills have accumulated comfortable fortunes, should be displaced only with great difficulty by new methods, theoretically improvements, but practically in use but a short time.

The early experience, filled with failure in the use of rotating cylinders at Grand Rapids and Alabaster has not been forgotten, so new methods reported as successful in New York and Pennsylvania are looked upon with suspicion by the practical operators in this State who are familiar with the past history of these early Michigan cylinders. This experience of opposition to new methods is seen in many lines of industry. It was prominent some years ago when rotary kilns were invented for use in Portland cement manufacture.

The buildings in the Michigan plant are built in a substantial manner of brick or heavy frame. The older mills are built compact with the different rooms under one large roof, or grouped close together. The new plants have separate buildings and if not built of brick, have at

least the engine room so constructed. Fire has destroyed many of the gypsum mills and every precaution is used to avoid the danger of fire.

§ 6. Use of Retarders.

Plaster of Paris made from gypsum rock will set in a few minutes, but if a retarder can be added, it will delay the set for a longer time according to the amount added. In ordinary cases enough retarder is mixed with the plaster in the Broughton mixer to delay the set about two hours and occasionally by special order, the set is delayed six to eight hours. The retarder a few years ago was always added in the kettle which gave uneven and unsatisfactory results.

Various substances have been used for this purpose. In the earlier history of cement plasters, glue water was added by the workman as he used the material; but this was troublesome and often resulted in poor work from neglect to use the proper amount or failure to thoroughly mix the parts. The trade demanded a plaster already retarded in a way that would give uniform results. This has led to the invention and manufacture of patent retarders in large numbers.

These retarders have a base of some glue compound or hair treated with chemicals, and are organic in composition. The popular brands now in use are the Challenge, Webster City, Wymore, Binn's, Ohio, retarders. In Michigan the Wymore retarder is in common use. It is made of a mixture of organic compounds not patented, but the formula is carefully guarded, and it is made at Wymore, Nebraska.

Among the ancient Romans, blood was used to retard the set of plaster of Paris, and today the organic material of the tankage from packing houses is found to give the desired results and is used to a very considerable extent as a retarder. Among the numerous patents issued for retarders the following may be of interest:

Patent number 286,650 was issued to cover a mixture of plaster of Paris, saw dust, hair, and water.

Patent number 291,508 is for a mixture of plaster of Paris, weak glue water, glycerine, sawdust, and slaked lime.

Patent number 301,459 is a mixture of plaster of Paris and glue.

Patent number 445 211 calls for a mixture of a solution of the substance of hair.

Patent number 446,604 is a mixture of beans, peas, and lentils, with slaked lime, carbonate of soda, and alkaline earth.

Patent number 452,346 covers a mixture of plaster of Paris with glue dissolved in water, lime slaked in glue water, and sand.

Patent number 391,889 is for a mixture of plaster of Paris, sawdust, sugar, carbonate of soda, slaked lime, sand, pumice stone.

Patent number 397,297 is for a mixture of hydraulic lime, animal gelatin, and vegetable glutinous matter.

Patent number 321,620 covers the mixture of plaster of Paris and resin-de-lac dissolved in caustic soda.

Patent number 420,008 is a mixture of plaster of Paris, serum and hair mixed, carbolic acid and air slaked lime.

Patent number 479,060 is a mixture of plaster of Paris, glue, seed meal, sulphate of zinc, cut rope or hair.

Patent number 523 658 is for the mixture of fermenting and decomposing organic matter in water mixed with quick lime dried and powdered.

Patent number 558,435 gives a complex mixture of plaster of Paris. furnace slag, slaked lime, hydraulic cement, flour of grain, and fibre.

Patent number 502,096 gives plaster of Paris, sanegal gum, sugar, silicate, carbonate of soda, alum, clay, salt cake, and ground China meal.

An examination of these specifications will show considerable resemblance in composition, and part of the materials included would appear to be only needed to add to the complexity of the mixture and enable one to secure a patent. Plaster of Paris is a common ingredient. Of the 40 patent specifications in my possession, 20 have a base of glue, and five of prepared hair, seven contain sawdust.

The cause of the retarding influence of such mixtures has never been fully determined. The set of plaster, as will be shown in another section, is due to the formation of a crystal network. This ordinarily takes place as soon as water is added to the calcined gypsum. The retarder delays in some way this crystallization, possible by holding the water, as dried organic tissues have a strong affinity for water. The water would then be given up slowly to the plaster and the crystallization be delayed.

In the laboratory crystals may be seen forming out of solution and then gradually increase in size. This is seen in some substances better than in others, but the cause of the phenomena has been a subject of speculation from the days of the early mineralogists of the time of Hauy at the beginning of the last century, but so far the explanation of the exact causes of crystallization has eluded the students of crystallography. Until the causes of crystal formation are understood, it will be extremely difficult if not impossible to explain the action of substances which act as retarders to crystallization.[1]

The force which produces crystals has been termed the crystallizing force and while this is a useful handle for grouping the observed facts, it lacks an explanation and definition. It seems without doubt to be a molecular force and is exerted in different ways in different substances, and different ways in the same substance under different conditions.

[1]Glues increase viscosity hence retard circulation. The growing crystal soon exhausts its immediate neighborhood and new material is only slowly fed in. See Rosenbusch p. 28, Microscopische Physiograpie.

The retarder as added to plaster is in proportion of 4 to 6 pounds to the ton, or in 1 pound there would be about 1-30 of an ounce, and this is sufficient to delay the set 3 or 4 hours.

If the retarder holds the water as suggested above, the plaster would not be injured by such addition of foreign material in small amount, as it would only delay the time of the formation, and the resulting crystal network would be as strong as though no retarder was there, but experiments show that the plaster is weakened, and there must be some other result in addition. A series of experiments was made to determine the effect of the retarder on the strength of the plaster. The following table shows the tensile strength in pounds per square inch of plaster of Paris plus Wymore retarder after 30 days.

Mixture.	Pounds of retarder to ton.	Initial set.	Final set.	Average strength.	Maximum strength.
A.	0	2 min.	48 min.	595	667
B.	2	3 "	1 hour 49 min.	558	578
C.	4	1 hour 23 min.	7 hours. 43 min.	348	456
D.	10	1 hour 35 min.	....	325	495

With an addition of two pounds of retarder to the ton, the strength of the plaster is decreased over 6 per cent. This would indicate a direct effect of the retarder on the crystal arrangement preventing a perfect crystallization of the plaster. The reduced strength even with the addition of 10 pounds of retarder to the ton, would still give a plaster stronger than is really necessary for a wall, as it would never be subjected to a strain of 325 pounds to the square inch. But the excess of retarder, would through disintegration probably greatly weaken the plaster in course of time.

The proper treatment would be to use as little retarder as is necessary and to use the best that is made. The gelatins to which group glue belongs are composed of carbon, hydrogen, nitrogen, and oxygen, in very complex proportion, but they represent fairly stable compounds. Some of the refuse matter used for retarder is of very different character and in nature passes through the stages of decay and it seems but natural that they would alter even plaster.

Particles of foreign material added to plaster of Paris appear to act as accelerators, but when some of these are heated with the gypsum they act as retarders. The table shows a portion of an extended series of experiments on influence on set of plaster through the use of a variety of substances. The clay used was ordinary fine ground clay with a considerable percentage of moisture. This clay burned with the gypsum

rock held back the set. The dried clay seems to be a retarder and in that condition would have a strong affinity for water.

Mixture of plaster of Paris.	Initial set in minutes.	Final set in minutes.
Pure plaster of Paris	7	21
water acidulated with HCl	2	6½
" " " H_2SO_4	1½	4
with sodium carbonate	9	16
" " sulphate	4½	10
" concentrated sugar solution	5	12½
" borax	4½	12
" wood charcoal	7	12½
" limestone	7	16
" one-third sand	7	15
" 1% limestone	11	23
" 6% "	13	24
" 10% "	10	19
" 2% clay	5	14
" 8% "	5½	15
" 10 "	5	15

An inspection of this table shows that the different proportions of clay and even of limestone make but little difference in the time of setting. Acids and sulphates when added in nearly saturated solutions hasten the set. Sugar solutions were formerly added for retarder, but in nearly saturated solution they hasten the set.

§ 7. The Set of Plaster.

When water is added to plaster of Paris, it sets in a solid mass. This is all that it is necessary for the plasterer to know in order to do his work, but to many of these men the subject of the true nature of the set is an interesting and puzzling problem. Just what is the process of setting of plaster?

Lavoisier Theory.

As far as we can learn from the chemical and physical literature, this question was first answered by that famous French chemist, Lavoisier, who in 1765 described the results of his experiments in the following words, translated from the French.[1]

"I took the calcined plaster, as has been described before, and which hardens readily with water. I threw it into a considerable amount of water, in a pan or large dish. Each molecule of plaster, in passing through the liquor, seized its molecule of water of crystallization, and fell to the bottom of the dish in the form of small brilliant needles, visible only with a strong lens. These needles, dried in the free air or with the aid of a very moderate heat, are very soft and silky to the touch. If placed on the stage of a microscope, it is perceived that what was taken under the lens for needles are also parallelopipeds, very fine, so they are described as thicker, or many times thinner, and many more elongated. The plaster in this state is not capable of uniting with water, but if it is calcined anew, these small crystals lose their transparency

[1]Quoted by Landrin. Annales de Chimie, pp. 431, 435; 1874.

and their water of crystallization, and become again a true plaster, as perfect as before. One may, in this fashion, successfully calcine and recrystallize the plaster even to infinity, and consequently give it at will the property of seizing water."

This explanation of the set of plaster through the formation of a crystalline network was verified a number of times later, and was given by Payen in 1830 as his first principle in the chemistry of plasters.

Landrin's Theory.

The next important contribution to the chemistry of plaster was by Landrin in 1874, who divided the set of plaster into four periods.

"1. The calcined plaster, on contact with the water, united with this liquid and takes a crystalline form.

"2. The plaster dissolves partially in water, which becomes saturated with this salt.

"3. A part of the liquid evaporates, due to the heat set free in the chemical combination. A crystal is formed and determines the crystallization of the entire mass; a phenomenon which is analagous to that which takes place when a piece of sulphate of soda is placed in a saturated solution of this salt.

"4. The maximum hardness is reached when the plaster gains enough water to correspond exactly with the formula $CaOSO_3$, $2H_2O$; this maximum being to the remainder in proportion to the quantity of water added to the plaster to transform it into mortar."

Chatelier's Theory.[1]

Chatelier in 1887 showed that plaster would set in a vacuum flask. so that evaporation was not a necessary step in the set of plaster, as Landrin maintained in his third principle above.

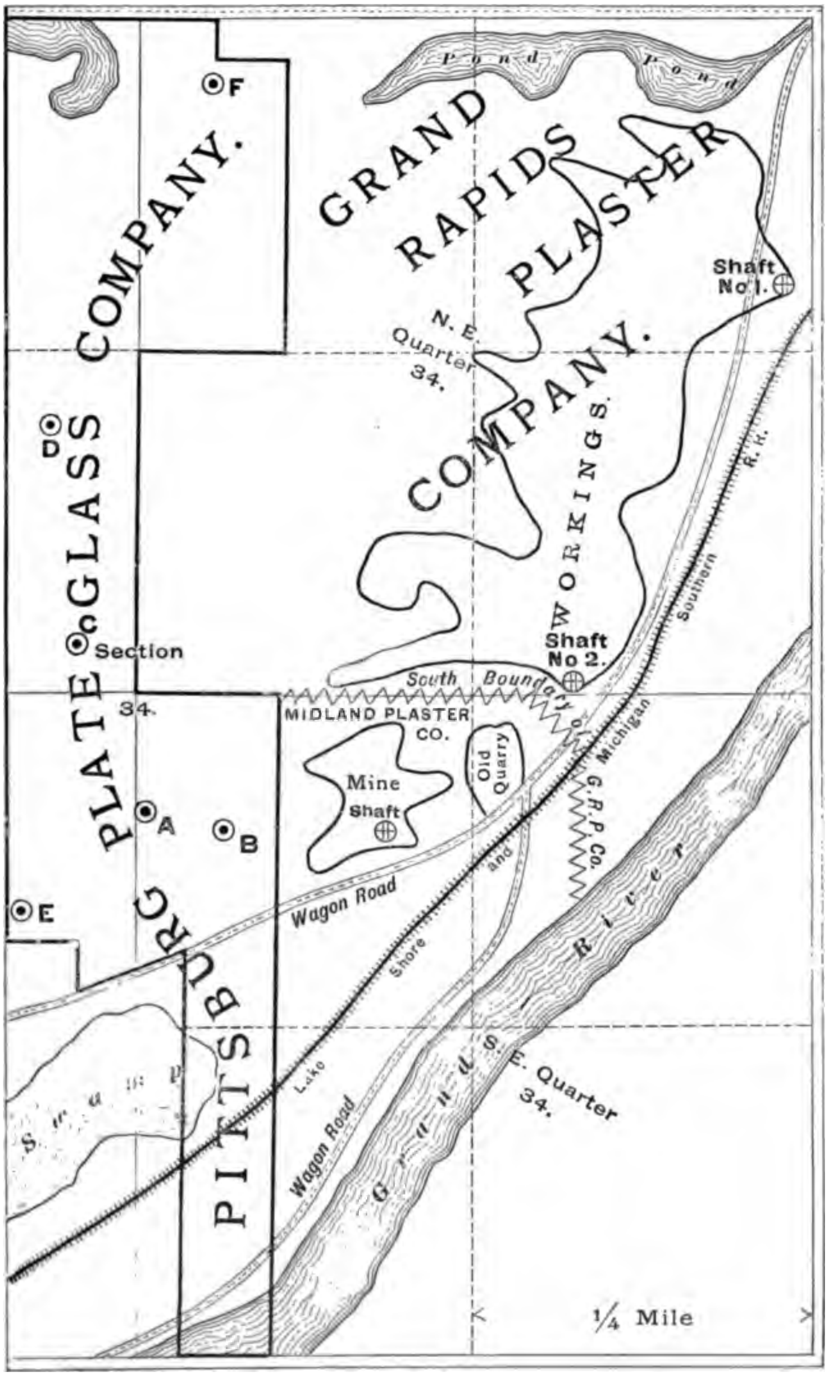
According to Le Chatelier, the plaster of Paris compound $(CaSO_4)_2$. H_2O dissolves in part in the added water, which diminishes the solubility, and the solution becomes therefore supersaturated and $CaSO_4$, $2H_2O$, or gypsum, crystallizes out. In other words, the plaster of Paris dissolves, and becomes hydrated, then crystallizes out as gypsum, and every particle of the plaster goes through these steps.

Grimsley Theory.

In Volume V of the University Geological Survey of Kansas, the writer outlined a theory to explain the setting of plaster. This theory was based on a number of laboratory experiments and on careful observation. Since that time a considerable amount of time has been devoted to this subject and the theory still appeals to me as a logical and plausible one, fully in accord with the observed facts.

[1] Academie des Sciences 1887.

NORTH



PITTSBURG PLATE GLASS COMPANY LANDS.

Under the microscope the ground gypsum before calcination consists of rather large masses of varying size as shown in Figure 31. In comparison with the gypsum earth, the rock is seen to consist of more or less broken crystals, while the gypsum earth shows crystals of more regular shape. After calcination these larger crystals are found to be broken into fine granules of nearly uniform size and shape. As the material is heated, the water is changed to steam throughout the crystal

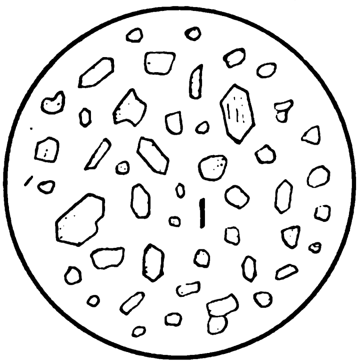


FIG. 31. Uncalcined gypsum earth, × 500 diameters.

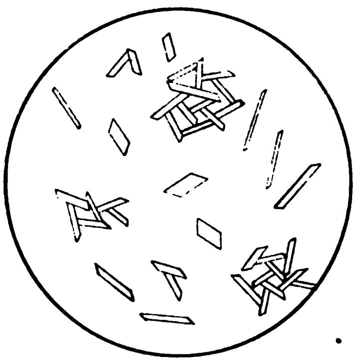


FIG. 32. Calcined gypsum earth from central Kansas, one-half hour after water was added to it, × 600 diameters.

mass, and expanding, breaks the crystals into finer particles. There is thus a physical change as well as a chemical one. If the plaster has not been sufficiently calcined the grains are coarser and more irregular.

Under the microscope when water is added to the calcined plaster, small needle like prisms are seen forming and shooting out here and there. As these become more and more abundant, they unite with one another and rapidly form a solid mass, in which the individual crystals can scarcely be distinguished. Open spaces are left in the mass apparently filled with water, and finally these are closed, and a firm solid mass results. The network formed by these crystals at first, is shown in the drawing in Figure 32.

The treatment of calcined gypsum with water in the same way shows very little change, Figure 33. Gypsum crystallized from solution by evaporation shows crystals which are not needle shaped, but they are broader and show considerable irregularity. They are more or less twinned and they do not interpenetrate, but form a loose mass which readily crumbles. This crystallization is shown in Figure 34, which was obtained by evaporating a solution of uncalcined gypsum on a glass slide and then examining it under a high power microscope.

Crystallization is aided by the small size of the grains or particles in the plaster, and the finer grained plasters set more rapidly than the coarser ones, as one may observe in the fine dental plasters as compared with ordinary plaster of Paris.

My own experiments agree then with those given by Lavoisier, Payen, Landrin, and Chatelier, in that the set of plaster is due to the formation of a crystalline network. The cause of the formation of this network of crystals, or the factor which starts the crystallization is the troublesome part to explain, and this has attracted less attention among investigators along these lines.

When gypsum is burned it forms, as Landrin showed and as analyses prove, the hydrate $(CaSO_4)_2$, H_2O. Marignac called attention to the fact that if the water is added in excess, this hydrate in part is dissolved, forming first a clear liquid which then becomes turbid, and crystals of $CaSO_4$, $2H_2O$, or gypsum are thrown down. Now an examination of these formulæ shows that three parts of water have been taken up by the hydrate.

FIG. 33. Uncalcined ground gypsum in water, after standing three days.

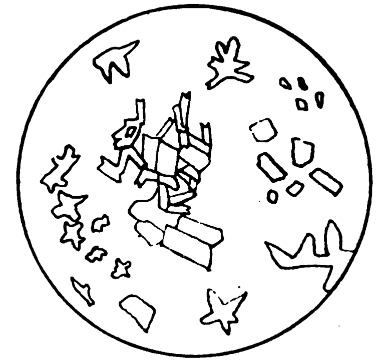


FIG. 34. Gypsum crystallized from solution in water, after standing three days.

$$(CaSO_4)_2, H_2O + 3H_2O = 2\ (CaSO_4, 2H_2O).$$

So first the plaster dissolves partially in contact with the water, as Landrin pointed out in his second principle, and as accepted by Chatelier. Next, some changes take place whereby, according to Mariginac's experiment, the liquid becomes turbid and crystallization begins. Landrin thought evaporation took place as a result of the heat formed by chemical combination, and that then a crystal was formed which started the crystallization through the entire mass. Chatelier showed by experiment that evaporation was not necessary and he argued that by the taking up of this water the solubility of the hydrate was decreased, and so, on account of the resulting supersaturation, crystallization ensued.

The solution of the hydrate in these experiments is certainly saturated, and all that is needed is something to start the crystallization. From a study of saturated solutions in the laboratory, it is well known that if crystals are introduced into such solutions crystallization will result and go on until the salt is crystallized out.

The effect of heat on gypsum in the burning of plaster, as we have shown, is to remove a certain percentage of water and to break up the small masses of the rock into finer and finer particles, microscopic and ultra-microscopic in size. If the heat is not carried too far certain particles through the mass may still possess their crystalline form as shown in Figure 31, and so they are true crystals though very small. These minute crystals in the saturated solution would start the process of crystallization. Their growth would cause the turbidity of the solution as noted by Marignac, and would result in the precipitation of small gypsum crystals, thus forming the crystal network which constitutes the set of plaster.

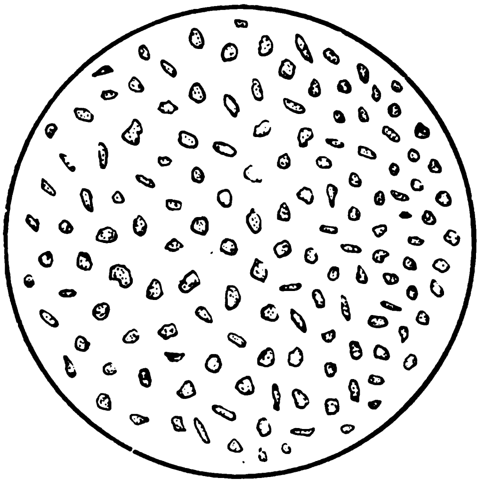


FIG. 35. Calcined gypsum earth from central Kansas, × 500.

If the plaster is unburned the gypsum is not reduced to the proper fineness and uniformity, and so would not permit the crystallization to go on in the way it would in the properly burned plaster. But of more importance, the hydrate represented by plaster of Paris would not be formed.

If the plaster is overburned, the plaster will be so completely comminuted that no minute crystals would be left to start the crystallization. Where the plaster is slightly overburned, the crystals are extremely fine and crystallization goes on very slowly and imperfectly.

CHAPTER IX.

CHEMISTRY OF GYPSUM AND GYPSUM PLASTERS.

§ 1. Composition.

Gypsum was used in a variety of ways long before its real nature and composition were determined or even investigated. The first record of the composition of gypsum is found in a paper of Lavoisier presented to the Academie des Sciences in 1765. Lavosier decomposed the gypsum rock by means of carbon, setting free sulphurous vapors which formed a sulphur deposit and proved the presence of sulphuric acid. He then decomposed a solution of gypsum in water by means of potash, showing the presence of lime. In this manner the qualitative analysis of gypsum rock was made and its elements determined.

Later quantitative analyses were made on various specimens of gypsum. One of these early analyses was made on pure crystallized gypsum from Mont-martre near Paris. This analysis shows a very low percentage of water, and indicates rather anhydrite.

	Per cent.
Silica	0.02
Lime sulphate	92.56
Lime carbonate	0.32
Water	7.10
	100.00

From this and other similar analyses, the theoretical composition of a pure gypsum was determined, and by later revision was given as,

	Per cent.
Sulphuric acid	46.60
Lime oxide	32.50
Water	20.90
	100.00

The percentage composition of water (20.9) and lime sulphate (79.1). divided, respectively by the atomic weights (water) 18, and (lime sulphate) 135, would give a proportion of the groups in the molecule, for water as 1.162 and for lime sulphate as .585, or a relation of two parts

of water to one of lime sulphate expressed by the chemical formula $CaSO_4$, $2H_2O$. When the two parts of water are absent the mineral is called anhydrite.

A portion of the water in the gypsum is readily removed on application of heat, and observation accompanied by chemical analysis shows that about three-fourths of the water can be readily removed, and the other one-fourth only with difficulty; and further that the three-fourths so removed passes off at two different stages.

§ 2. Payen's Experiments.

The facts noted above were first determined by Lavoisier and confirmed by Payen[1] in 1830, who found that the gypsum began to lose water at a temperature of 115° C., and that the loss rapidly increased up to 204° C. He determined the best temperature for the formation of plaster to lie between 110 and 120° C. (230 to 248° F.). In modern plaster manufacture a temperature of 100° or more higher than Payen's is used.

Payen's results are given in the following summary:

1. The set of plaster is due to a crystallization of hydrous sulphate of lime.
2. The lowest temperature at which plaster can be made is 80° C. (176° F.), but the material must be kept at this temperature for a considerable period of time.
3. A temperature of 110 to 120° C. is sufficient to deprive plaster of all its water and to calcine it completely.
4. Plaster in small particles favors drying.
5. Calcium sulphate heated to about 250° C. (482° F.) is dehydrated; at 300 to 400° C. (572 to 752° F.) it loses completely the properties of hydration, or the power of gaining again the water of crystallization, and resembles then the hydrated sulphate of lime found in nature. If heated higher, it may result in melting the sulphate of lime.
6. The hardening of plaster by alum is perhaps due to the formation of a double sulphate of potash and lime.

§ 3. Chatelier's Experiments.

Chatelier[2] in 1887 conducted some very elaborate experiments on the effects of temperature on gypsum. He powdered the gypsum rock and placed it in a paraffin bath, and connected a thermometer in the bath with a chronograph. On applying heat up to 200° C. or 392° F., there was a constant rise in temperature, with two exceptions. The first halt occurred at 128° C. or 262° F., and the second at 163° C. or 325° F. The first one was the more pronounced, and Chatelier regarded these

[1] Chimie Industrielle, 1830, quoted by Landrin, Annales de Chimie, 1874.
[2] Annales des Mines, p. 345, 1887.

interruptions as due to an absorption of heat which accompanied the elimination of water. This would indicate the existence of two different hydrates, whose decomposition took place at the temperatures indicated by the halts on the chronograph. Further the dehydration was found to be incomplete at 155° C. or 311° F., and complete at 194° C., or 381° F.

In order to prove the composition of the first hydrate, Chatelier heated a saturated solution of gypsum in a closed tube to a temperature between the two halts indicated, or between 130° C. (266° F.) and 150° C. (302° F.) and very delicate, long, rectangular prisms were formed, which were thrown into alcohol and then analyzed with the following result:

	Per cent.
Water	6.70
Sulphate of lime	93.30
	100.00

This agrees very closely with the formula $(CaSO_4)_2, H_2O$, where there would be,

Water	6.20
Sulphate of lime	93.80
	100.00

In this compound it is seen that two parts of lime sulphate are united with one part of water, while in the original gypsum one part of lime sulphate was united with two parts of water. Chatelier also found that the incrustation in the boilers of ocean steamers, where salt water was used and where the temperature averages about 165° C. (320° F.), possessed nearly the same composition as the hydrate given above. His analysis was as follows:

Water	5.80
Sulphate of lime	91.90
Carbonate of lime	0.30
Iron oxide	2.00
	100.00

Further experiments by Chatelier showed that if 10 grammes of powdered gypsum were heated for some time at 155° C. or 311° F., intermediate between the temperatures necessary for the decomposition of the two hydrates, the loss in weight was uniformly 1.56 grammes which corresponds with one and a half equivalents of water so that the compound should contain about 6.2 per cent of water as shown by the formula given. Ordinary plaster of Paris usually contains about 7 per cent of water, so that it is a definite hydrate with the formula $(CaSO_4)_2, H_2O$.

The second halt, as has been given, took place at 163° C. or 325° F. From this temperature to 221° C. or 430° F. no change was noted in the plaster; but beyond this temperature, the plaster when mixed with water did not absorb it readily and only set after a long time. If the heat reaches 343° C. or 650° F., the plaster acts like anhydrite, and it is said to be dead burned and will not set on addition of water. If the gypsum is heated further, the substance melts, forming a crystalline mass on cooling which cannot be decomposed by heat except in the presence of organic matter, when it changes into CaS. If this substance is acted upon by carbon dioxide gas (CO_2) and water, sulphuretted hydrogen gas will be formed.

The temperature of burning is thus seen to be all important, and calls for skill and experience on the part of the calciner. If overburned, the plaster sets very slowly. If underburned, the new hydrate is not formed, and the plaster will not set.

§ 4. Chemistry of Foreign Gypsum.

In the various papers on foreign gypsum deposits so far as consulted, very few analyses are given. The gypsum of the Hartz[1] mountains is a pure variety containing but little silica and iron, while the analysis from the Philippines shows a higher percentage of the silica impurity.

	Wienrode Hartz by Jungst.	Osterode Hartz by Hampe	Albany Philippines by Trobe.
Silica and insoluble residue	2.80	0.15	6.43
Iron and alumina oxides	0.60	......	0.64
Lime sulphate	77.63	79.05	73.60
Lime carbonate	.....	......	......
Water	19.90	20.74	20.18
	100.93	99.94	100.85

In New South Wales[2] the gypsum is not as yet used to any extent, and may be compared with the rock on St. Marcos island off the coast of California analyzed by the writer, and also with the analysis of the gypsum of Hawaii.

	Lake Tank, north of Bourke, New South Wales.	St. Marcos, by Grimsley.
Silica and insoluble residue	2.90	0.16
Iron and alumina oxides	0.60	0.31
Lime sulphate	75.66	78.60
Lime carbonate	.....	0.93
Water	20.20	20.31
Magnesia sulphate	0.61	......
	99.97	100.31

[1] Calculated from analyses given in Vol. V, Univ. Geol. Survey. Kans., p. 141.
[2] Minerals of New South Wales, p. 164, 1888.

The analysis from Hawaii[1] shows a very high percentage of lime, and would give about 76.04 per cent of lime sulphate, and leave about 7 per cent for water, i. e., anhydrite.

Silica and insoluble residue	4.00
Iron oxide (Fe_2O_3)	0.70
Lime oxide	43.40
Sulphuric acid	44.73
Magnesia oxide	0.50
	93.33

§ 5. Canada Gypsum.

In Canada over four-fifths of the gypsum quarried is exported, and most of this rock comes to the United States. The leading district for the gypsum sent to this country is in Nova Scotia. Analyses[2] of this rock are given in the following table which shows the percentage of sulphuric acid and also the calculated percentage of the combined sulphate of lime plus water.

	No. 1.	No. 2.	No. 3.	No. 4.
Sulphuric acid	43.65	43.98	40.84	44.86
Water	.....	......	18.47	20.02
Insoluble in acids	1.88	2.67	0.99	2.57
Undetermined	4.28	2.77	11.20	0.97
Sulphate of lime and water (gypsum)	94.84	94.56	87.81	96.46
	101.00	100.00	100.00	100.00

§ 6. United States Gypsum.

The gypsum rock from eastern United States to the Pacific coast shows a considerable range in chemical composition. In the eastern part in New York state the composition is shown in the following analyses:

	Cayuga.[3]	Onondaga.[4]		N. Y. Rock,[5] Prof. Armsby.
Lime sulphate and water (gypsum)	74.09	64.53	73.92	76.35
Insoluble matter	6.05	11.17	4.64	5.83
Other material chiefly $CaCO_3$	19.86	24.27	21.44	17.82
	100.00	99.97	100.00	100.00

The average composition of the New York gypsum rocks is given by Merrill as,

	Land plaster.[6]	Severance quarry.[7]
Lime sulphate and water (gypsum)	65 to 75%	80 to 90%
Insoluble material	6 to 8%	10% or less.
Lime carbonate	18 to 28%	Trace.
Magnesia carbonate	....	5% or less.

[1] 19 Annual Report U. S. Geological Survey. Part VI, Cont., p. 685; 1897-8.
[2] Report of Connecticut Exp. Station, p. 62; 1883.
[3] Report Connecticut Exp. Station, p. 75; 1884.
[4] " of same station, p. 62; 1883.
[5] Advertising Circular Marsh & Co., Sandusky, Ohio.
[6] Report Connecticut Exp. Station, p. 50; 1882.
[7] Bulletin New York State Museum. Vol. III, p. 81; 1893.

BUHR STONE MILLS, GRINDING GYPSUM; GRAND RAPIDS PLASTER COMPANY.

OHIO.

Going farther west, the gypsum industry is seen to center in a small district near Sandusky in Ohio. This rock, according to the late Professor Orton, has the following composition:[1]

	Average sample.	Surface rotten rock.	Land plaster.
Silica and insoluble material	0.68	0.46	0.91
Iron and alumina oxides	0.16	0.29	0.60
Lime sulphate	77.45	78.54	78.73
Lime carbonate	1.12	0.75	.....
Water	20.14	20.00	19.70
Magnesium oxide	0.56	0.03	0.54
	100.11	100.07	100.48

FLORIDA.

An analysis of a gypsum deposit in Florida is given by Dr. David T. Day, as,[2]

	Per cent.
Silica and insoluble material	0.07
Iron and alumina oxides	0.01
Lime sulphate	77.79
Lime carbonate	0.52
Water	21.39
	99.78

IOWA.

The composition of the Iowa gypsúm is given in the following analyses by G. E. Patrick:[3]

	Selected sample.	Top.	Middle.	Bottom.
Insoluble residue	0.65	......	......	......
Lime sulphate	78.44	78.37	78.54	78.44
Water (calculated)	20.76	20.75	20.79	20.76
	99.85	99.12	99.33	99.20

KANSAS.

In Kansas a very complete chemical examination was made by Prof. Bailey of the gypsum rocks and plasters. From these a few are selected to show the range in composition of the gypsum rock, and a second series gives the composition of the gypsum earth so much in demand in that section for the manufacture of plasters.[4]

[1]Calculated from Geol. Survey of Ohio, Vol. VI, pp. 696-702; 1888.
[2]Calculated from U. S. Geol. Survey, Vol. XX, Part VI Cont., p. 662; 1899.
[3]Iowa Geological Survey, Vol. III, p. 291; 1895.
[4]Univ. Geol. Survey of Kans., Vol. V., pp. 146-147; 1899.

	Blue Rapids.	Dillon.	Medicine Lodge.
Silica and insoluble material.	0.65	0.35	0.19
Iron and alumina oxides	0.17	0.12	0.10
Lime sulphate	79.30	78.40	77.46
Lime carbonate	1.53	0.56	1.43
Water	18.84	19.96	20.46
Magnesium carbonate	0.39	0.57	0.34
	100.88	99.96	99.98

Kansas Gypsum Earth.[1]

	Dillon.	Burns.	Longford.
Silica and insoluble material	12.13	2.31	10.23
Iron and alumina oxides	0.99	0.37	1.12
Lime sulphate	64.63	67.91	58.75
Lime carbonate	3.57	11.71	11.77
Water	18.75	17.72	17.10
Magnesium carbonate	0.88	0.52	0.94
	100.95	100.54	99.91

Oklahoma, Indian Territory, and Texas Gypsum Earth.

	Marlow, I. T.[2]	Okarche, O. T.[3]	Quanah, Tex.[4]
Silica and insoluble material	10.67	7.98	0.91
Iron and alumina oxides	0.60	0.50	0.21
Lime sulphate	59.46	71.70	69.92
Lime carbonate	10.21	1.14	9.05
Magnesium carbonate	1.10	0.24	0.65
Water	16.59	18.68	18.85
	98.63	100.24	99.59

COLORADO AND WYOMING.

	Aspen District, Colorado.[5]	Red Buttes, Wyoming.[6]
Silica and insoluble material	1.46	4.50
Iron and alumina oxides	......	1.27
Lime sulphate	69.26	64.22
Lime carbonate	5.96	15.74
Water (calculated)	21.50	14.00
Magnesium carbonate	1.32	......
	99.50	99.73

CALIFORNIA.

The gypsum deposits of California have been worked from time to time, but at the present time only one deposit is worked and this is near Los Angeles. The analyses are given as follows:[7]

[1] Univ. Geol. Survey of Kansas, pp. 149, 152, 154.
[2] Univ. Geol. Survey of Kansas, Vol. V., p. 149; 1899.
[3] Furnished by the O. K. Cement Plaster Co.
[4] Wilkinson, The Technology of Cement Plaster, p. 5; 1897.
[5] Calculated from U. S. Geol. Survey, Mono., XXXI, p. 240; 1898.
[6] Furnished by Prof. Wilbur C. Knight.
[7] Univ. of California Exp. Station, 1891-2.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Silica and insoluble material..	2.2	1.4	4.8	14.3	13.0	6.0
Calcium sulphate and water..	88.8	88.9	83.2	72.0	87.0	72.6
Calcium carbonate..........	9.0	9.7	12.0	3.9	....	22.0
Other materials.............	....	....	....	9.8	....	....
	100.0	100 0	100.0	100.0	100.0	100.6

No. 1, Coalinga. No. 2, Nevada Gypsum and Fertilizing Co. No. 3, Bakersfield mine. No. 4, Southern California. No. 5, San Francisco. No. 6, Los Angeles.

A comparative study of these various analyses shows that the range of gypsum (lime sulphate and water) varies from 64.53 per cent at Onondaga, N. Y., and 72 per cent in Southern California, to 99.18 on Bear Island, Florida and 99.50 in Iowa.

The gypsum of Florida, Iowa, Ohio, Kansas, will average close to 99 per cent purity. The Canada gypsum will run about 94 per cent. The California rock gypsum runs about with the gypsum earths of Wyoming, Kansas, Oklahoma, and Texas, ranging from 80 to 85 per cent.

The silica impurity is under 1 per cent in Ohio, Florida, Iowa, and Kansas; but according to the analyses given it is 4 to 6 per cent in New York, and up to 14 per cent in some of the California rock. Lime carbonate ranges around 1 per cent in most of the gypsum rock of the United States. The theoretical percentage of water is 20, and the rocks analyzed show a per cent ranging from 17.82 to 24.27.

The average per cent of lime sulphate and water, or gypsum in the analyses of the U. S. gypsum rock quoted in the preceding analyses is 92.75; or leaving out the New York and California analyses would give 97.38 per cent.

The difference in percentage of lime sulphate in favor of some deposits is often taken advantage of, for advertising purposes, but the gypsum in this country is usually of high grade of purity in the areas worked for plaster, and makes a good product. The centralization of the plaster industry in certain states is due not so much to the purity of the material, as to the extent of the deposits, nearness to railroad markets, and to the business enterprise of the people forming the companies.

§ 7. Chemistry of Michigan Gypsum.

Having passed in review the chemical nature of the various gypsum deposits in this and other countries, it now remains to examine the deposits of this state, where gypsum of marked purity can be found, and where one of the leading centers of the industry is established by the causes given in the preceding paragraph.

The chemistry of Michigan gypsum has been discussed from the beginning of the industry. Some of the old records hasten to state that the gypsum of this state is the purest in the country, a statement naturally disputed by the workers of other states. In any section it

is possible to select exceptionally pure specimens of gypsum rock whose analysis approaches very closely the theoretical percentage called for by the formula. On the other hand it is possible to select portions of rock impregnated with clay and other impurities which will give an analysis showing an exceptionally poor rock. In making comparative examinations, or in giving the composition of a quarry, it is essential that careful samples be taken not from one place alone, but from different parts of the quarry. Not knowing in all cases just how the specimens were selected from which the analyses were made as given in the foregoing pages, it would not be just to draw conclusions as to the best deposits in the country, or to say where the poorest are found. Again the effect of the so-called impurities is not always known. Some of these may be beneficial. Lime carbonate in marked quantity in gypsum is usually regarded as a useless impurity in this country; but in the Paris gypsum the 12 per cent of lime carbonate is said by some authorities in that country to explain the greater strength of Paris plaster over the plaster in some other countries. The presence of alumina in amounts of two and three per cent is said to act as a retarder in the set of plaster.

Method of Sampling.

In the present work, an attempt was made to secure average samples, and this was accomplished by taking the specimens from the spouts into the buhr mills. This partially crushed rock coming from various parts of the quarry represents the rock actually ground and made into plaster. An amount of about two or three pounds weight was taken and divided. The part selected was again divided and crushed to a fine flour, and then divided and a portion ground to the finest powder in an agate mortar. One gram of the powder was taken for analysis. This method would give a lower proportion of the compounds than would be given by carefully selected pure specimens. The results may not be so valuable for advertising purposes when compared with analyses made from carefully selected samples in other districts, but should compare well with those made by the chemists of our state surveys.

The samples collected for the Kansas work were selected in a somewhat different way, but with the same object in view of determining the average quarry composition. In that state the specimens collected by the writer, were taken from various parts of the quarry, crushed and then divided two or three times and a few pounds weight were taken and sent to the laboratory where it was further divided and crushed.

Method of Analysis.

The method of analysis used on the Michigan material is based on the methods used by Prof. Bailey of the Kansas work and was as follows:

One gram of the powdered gypsum was dissolved in concentrated hydrochloric acid in an evaporating dish and evaporated to dryness on a sand bath until all odor of HCl had disappeared. The mass was then digested with dilute acid and boiled several times. A single boiling was found to leave a heavy apparently insoluble residue, which was greatly decreased on the second and third boiling. This portion of the analysis should be watched carefully so as to make sure that the lime sulphate all goes into solution. The solution is then filtered and the silica or insoluble material on the filter is washed with hot water, dried, ignited and weighed.

The filtrate is diluted to 500 c.c., and thoroughly mixed; 300 c.c. are taken for the determination of the bases, and 200 c.c. for sulphuric acid. In the first portion iron and alumina are precipitated with ammonia, and the precipitate filtered, washed with hot water, dried, ignited, and weighed. To this filtrate heated to boiling is added a hot solution of ammonium oxalate and the precipitate of oxalate of lime after standing a few hours is readily filtered, and after drying may be treated with sulphuric acid (H_2SO_4) converting the oxalate to sulphate of lime which multiplied by 7-17 will give the amount of oxide of lime (CaO). The magnesia if present in the filtrate is precipitated with sodium phosphate, which, filtered, dried, weighed, and multiplied by .756 will give the amount of (MgO), magnesium oxide.

The other portion, 200 c.c. treated with barium chloride (BaCl) will give a precipitate of barium sulphate ($BaSO_4$), whose weight multiplied by .3435 will give the amount of sulphuric anhydride (SO_3).

One gram of the powdered gypsum heated in an open platinum crucible to a temperature of 200° C. will give a loss in weight representing the amount of water.

Such an analysis of a specimen of gypsum will give the simple compounds which can be united to show the probable composition of the rock. The sulphate of lime will equal the amount of sulphuric anhydride plus the amount of lime oxide equal to the sulphuric anhydride multiplied by .7, and the remaining portion of the lime oxide is probably combined with carbon dioxide (CO_2) whose amount may be determined by multiplying it by 11-14.

ANALYSES.

Western Michigan.

The analysis of the Alabastine quarry rock selected by the method given shows the following percentages:

	Per cent.
Silica and insoluble material	1.28
Iron and alumina oxides	1.825
Lime oxide	32.94
Sulphuric acid (SO_3)	44.697
Water	19.00
Magnesium oxide	trace
	99.742

By calculation of this analysis the probable composition of the rock would be:

	Per cent.
Silica and insoluble material	1.28
Iron and alumina oxides	1.825
Lime sulphate	75.984
Lime carbonate	1.951
Water	19.00
Magnesium carbonate	trace
	100.04

The lower course of rock in this quarry, red in color, was formerly rejected as being too impure for finished plaster and was only suitable for rough uses as land plaster, but at the present time this rock is used with the rest of the quarry rock. Its analysis shows that the red color is not a badge of impurity.

	Per cent.
Silica and insoluble material	0.505
Iron and alumina oxides	trace
Lime oxide	32.90
Sulphuric anhydride (SO_3)	45.114
Water	20.57
	99.08

The analysis would give a probable rock composition of:

	Per cent
Silica and insoluble material	0.505
Iron and alumina oxides	trace
Lime sulphate	76.74
Lime carbonate	2.39
Water	20.57
	100.205

Across the Grand river from the Alabastine quarry in the English shaft mine, the gypsum rock has practically the same composition.

	Per cent.
Silica and insoluble material	1.18
Iron and alumina oxides	1.87
Lime oxide	32.74
Sulphuric anhydride	44.72
Water	19.00
	99.51

Calculating the probable composition of the rock gives:

	Per cent.
Silica and insoluble material	1.18
Iron and alumina oxides	1.87
Lime sulphate	76.02
Lime carbonate	2.57
Water	19.00
	100.64

In the same neighborhood a short distance east is the cave mine of the Grand Rapids Plaster Co., mill No. 2, where the rock has the following composition:

	Per cent.
Silica and insoluble material	1.245
Iron and alumina oxides	0.495
Lime oxide	33.115
Sulphuric anhydride	45.40
Water	19.03
	99.285

Calculating this analysis, gives the probable composition of this rock as:

	Per cent.
Silica and insoluble material	1.245
Iron and alumina oxides	0.495
Lime sulphate	77.186
Lime carbonate	2.380
Water	19.03
	100.336

Passing to the southwest five miles at Grandville, the Durr quarry rock has a composition as indicated in the analysis below:

	Per cent.
Silica and insoluble material	1.06
Iron and alumina oxides	0.325
Lime oxide	33.095
Sulphuric anhydride	44.13
Water	19.72
	98.33

The probable composition is then:

	Per cent.
Silica and insoluble material	1.065
Iron and alumina oxides	0.325
Lime sulphate	75.017
Lime carbonate	3.936
Water	19.72
	100.063

The bright selenite plates found in this quarry do not show much purer composition than the compact rock.

	Per cent.
Silica and insoluble material	0.35
Iron and alumina oxides	.....
Lime oxide	32.78
Sulphuric anhydride	45.61
Water	20.59
	99.33

Calculated:

	Per cent.
Silica and insoluble material	0.35
Iron and alumina oxides	.....
Lime sulphate	77.537
Lime carbonate	2.085
Water	20.59
	100.562

Winchell in the 1860 report,[1] (pp. 163 and 164) gives the following analyses of the Michigan gypsum:

Silicic acid	trace	.....	
Alumina and iron oxide	.5354	3.89	loss
Lime oxide	32.0385	32.67	
Sulphuric acid (SO_3)	46.2257	44.44	
Potassia	.2115	.....	
Soda	.0140	.....	
Chlorine	.0078	.....	
Water	20.8445	19.00	
	99.8774	100.00	

[1] The one by L. R. Fisk, the second by S. P. Duffield.

TOP OF GYPSUM KETTLES. MILL OF GRAND RAPIDS PLASTER CO.

Alabaster.

In the Alabaster quarry, probably the largest gypsum quarry in the United States, the average analysis shows the following composition:

	Per cent.
Silica and insoluble material	0.555
Iron and alumina oxides	trace
Lime oxide	33.155
Sulphuric anhydride	45.745
Water	20.28
	99.735

Calculated:

	Per cent.
Silica and insoluble material	0.555
Iron and alumina oxides	trace
Lime sulphate	77.766
Lime carbonate	1.86
Water	20.28
	100.461

Selected material from this quarry shows great purity, as given in the following analysis by Geo. H. Ellis, who states it is the finest gypsum he has ever analyzed. It would be possible to select a large quantity of such rock from this quarry.

	Per cent.
Lime sulphate	78.67
Water	20.98
	99.65

St. Ignace.

The deposits of St. Ignace in northern Michigan were analyzed, though only a small amount of material was available for the examination.

	Per cent.
Silica and insoluble material	0.195
Iron and alumina oxides	.....
Lime oxide	32.795
Sulphuric anhydride	45.845
Water	20.32
	99.155

Calculating the probable composition of this rock gives:

	Per cent.
Silica and insoluble material	0.195
Iron and alumina oxides	.....
Lime sulphate	77.936
Lime carbonate	1.257
Water	20.32
	99.708

At Grayling in the deep well, gypsum was found with a thickness reported as 132 feet, at a depth of 408 feet. This was analyzed as follows:

	Per cent.
Silica and insoluble material	19.08
Iron and alumina oxides	0.31
Lime oxide	29.755
Sulphuric anhydride	31.297
Water	14.10
	94.542

This gypsum is evidently a gypsum rock mixed with lime stone, and calculated gives:

	Per cent.
Silica and insoluble material	19.08
Iron and alumina oxides	0.31
Lime sulphate	53.20
Lime carbonate	13.92
Water	14.10
	100.61

The Michigan gypsum rock is seen from these analyses to range from 94.73 to 98.26 per cent of sulphate of lime and water, or in selected samples 99.65 per cent, with an average of over 97 per cent. This is slightly below the average in Ohio, Iowa, and Kansas. The real explanation of the difference is to be found in the excess of lime carbonate over the localities in Ohio, Iowa, and Kansas.

The silica impurity is but little over 1 per cent, and it is often less than this amount.

In calculating the probable percentages of the rock, the analyses usually run over the 100 per cent. This is explained in the Kansas gypsum by Bailey as due to a combination of some of the lime with the silica, which is decomposed in the process of getting the mineral into solution. It being impossible to tell how much of the lime to add to the silica, it was all computed as united with carbon dioxide (CO_2) in the form of carbonate of lime; and this gives a slight excess in the total of the compounds.

Anhydrite Analyses. L.

It will be noticed that I have stated that most of the calcium sulphate constituents at a considerable depth in wells, such as those of Alma, Mt. Pleasant, and Midland, and the series of the deeper wells in the Saline along the Detroit river, St. Clair river and the shore of Lake Michigan, is anhydrite. This is mainly based upon microscopic determinations. However, Mr. H. R. Browne of the Michigan Alkali Works at Wyandotte, made some tests of samples of their well (Ford No. 23) showing that the so-called gypsum is at least largely anhydrite. As the samples come up wet, a certain admixture of gypsum may come very easily from the water. We have also the results of an analysis of a sample from Mt. Pleasant as follows:

Analysis by M. A. Cobb, Oct. 26, 1903, of sample taken at 1,225 to 1,270 feet depth.

		Per cent.
	Fe_2O_3 } Al_2O_3 }	1.4
	$CaCO_3$	2.83
	MgO	.2
	$CaSO_4$	87.15
Difference, and	SiO_2, CO_2 } Moisture }	8.42
		100 00

The Michigan gypsum rocks are of high grade of purity and the plasters made from these rocks are standard products in the market.

§ 8. Chemistry of the Finished Plasters.

ANALYSES.

Plaster of Paris in France.[1]

	Silica.	Iron and Alumina.	Lime Sulphate.	Lime Carb.	Mag. Carb.	Water.
Vintry (Seine), ordinary...	4.9	2.5	70.9	10.2	5.05	6.45
" " fine..	3.7	2.7	72.6	12.0	5.45	3.55
Villejuif (Seine)............	4.8	0.6	77.95	8.5	1.9	6.25
Bondy (Seine), ordinary....	1.4	1.5	79.05	9.9	2.3	5.85
" " fine.........	2.4	1.0	83.4	6.9	2.3	4.0
Romainville (Seine)........	0.6	0.8	87.7	2.4	2.7	5.8
Bois le Comte (Seine)	1.2	0.35	85.75	4.3	....	8.4
Lamarche.................	1.6	....	88.45	3.75	....	6.2
Bussiere..................	1.05	0.45	84.0	7.15	0.4	6.95
Roquevaire (Bouches du Rhone)..................	11.2	3.1	70.55	6.7	5.65	2.8
Bassin de la Couze (Dordogne)...................	4.0	1.4	71.60	14.1	5.05	3.85
Herepain (Herault).........	4.2	1.0	81.6	....	...	13.2
Partel (Aude)..............	0.7	0.4	86.85	5.3	....	6.75
Malancene (Vaucluse)	0.6	....	92.0	0.35	....	6.15
Poligny (Jura).............	0.8	....	93.5	3.4	....	3.3
Grasse (Alpes-Maritimes)...	0.1	0.2	95.65	....	....	4.05

[1] Quoted from M. Durand Claye, Catalogue de Expos. de 1876. in Thorpe's Dictionary, Vol. 1. p. 470 474.

Ohio Calcined Plaster.[1]

	No 1.	No. 2.
Silica and insoluble material	0.68	0.46
Alumina	0.16	0.29
Lime sulphate	77.45	78.54
Lime carbonate	1.11	0.75
Water	20.14	20.00
Magnesia	0.56	0.03
	100.10	100.07

These analyses though given for calcined plaster were probably of uncalcined gypsum as indicated by the water percentage.

Wyoming Plaster.

The cement plaster made at Laramie, Wyoming, according to Slosson and Moudy has the following composition:[2]

	Per cent.
Silica and insoluble material	5.50
Alumina oxide	0.59
Lime sulphate	73.73
Lime carbonate	7.86
Water	6.93
Magnesium carbonate	3.04
Lime oxide	2.35
	100.00

Kansas Cement Plasters.

The gypsum plasters in Kansas are made from the rock and from the gypsum earth. These have been analyzed by Prof. Bailey with the following results:[3]

	Blue Rapids Rock.	Springvale Earth.
Silica and insoluble material	1.20	4.27
Iron and alumina oxides	0.20	0.47
Lime sulphate	89.42	83.55
Lime carbonate	1.68	3.07
Water	6.82	6.67
Magnesium carbonate	1.18	1.47
	100.50	99.50

1 Calculated from analyses in Mineral Resources. U. S. Geol. Survey, p. 600; 1887.
2 Tenth Annual Report Agricultural College of Wyoming, p. 8; 1900.
3 University Geol. Survey of Kansas, Vol. V, p. 160; 1899.

Texas and Oklahoma Territory.[1]

	Okarche, O. T.	Quanah, Tex.
Silica and insoluble material	13.29	2.53
Iron and alumina oxides	0.71	0.45
Lime sulphate	73.67	78.81
Lime carbonate	4.77	11.22
Water	5.78	5.70
Magnesium carbonate	1.91	0.74
	100.13	99.45

Heat of the proper degree applied to the gypsum rock changes it to plaster of Paris, through the loss of approximately three-fourths of the water. The formula of the calcined plaster $(CaSO_4)_2 . H_2O$, calls for 6.2 per cent of water and 93.8 per cent of calcium sulphate as has been explained in the early part of this chapter.

Many of the Paris plasters approximate very closely the theoretical percentage of water, but are usually low in the percentage of sulphuric anhydride as are all commercial plasters through the included impurities in the gypsum rock. The lime carbonate present in the rock is in all probability not altered in the change as the temperature is not sufficient to drive off the carbon dioxide (CO_2).

The Ohio analyses though given for calcined plasters were incorrectly labelled or the title represents a mistake in the proof. The Wyoming plaster and those of Kansas, Texas, and Oklahoma, show nearly correct amount of water for properly calcined plasters as determined by the theoretical percentages.

In some mills a few years ago and occasionally at the present time the plaster was drawn after the first settling. This method would enable the manufacturer to make plaster in a shorter period of time and so increase the capacity and lower the cost of fuel and labor. Such plasters have not been received with satisfaction by the trade.

In a specimen of the Michigan plaster obtained from one of the mills, the water percentage after the first settling was 6.67 and at the close of the second settling was 5.70 per cent. This analysis would not condemn the plaster in the first sample. It is similar to the amount in the Blue Rapids plaster of Kansas which is a standard grade of plaster. The second percentage agrees with the analyses given above of the Okarche, O. T., and of the Quanah, Texas, plasters. The physical tests of these materials and their relations to the chemical analyses are discussed under that chapter.

Prof. Bailey[2] has made an interesting series of analyses of the plaster

[1] Technology of Cement Plaster by Wilkinson, p. 5; 1897.
[2] University Geol. Survey of Kansas, Vol. V, p. 166; 1899.

in Kansas in different stages of the manufacture, which are given below as taken from the Kansas report:

	No. 1.	No. 2.	No. 3.	No. 4.	No 5.	No. 6.
Silica and insoluble material......	9.78	10.84	12.02	10.84	25.83	11.63
Iron and alumnia oxides.......... .	0.30	0.50	0.44	0.42	1.52	0 67
Lime sulphate......................	64.91	69.06	68.36	59.84	39.18	69.60
Lime carbonate.....................	6.12	9.37	14.39	10.50	24.15	11.74
Water	17.37	9.02	4.98	16.35	4.18	4.78
Magnesium carbonate.............	0.70	1.10	0.93	0.82	2 00	0.93
	99.18	99.89	101.12	98.77	96.76	99.35

No. 1. Crude material.
No. 2. Sample taken after two hours of boiling.
No. 3. The finished material.
No 4. A sample that has been set.
No. 5. The screenings or tailings.
No. 6. A sample that has been treated with a retarder.

These analyses show that one-half the water is expelled in the first two hours, and about one-fourth in the last hour. The plaster as set (No. 4) shows about the original percentage of water as found in the uncalcined rock. The tailings or screenings (No. 5) are high in silica, the oxides of iron, alumina and magnesia, and low in lime sulphate with a water percentage about normal for the finished product. An analysis of the retarded plaster (No. 6) shows practically no chemical difference from the non-retarded plaster. The amount of retarder added is so small that it is not detected by analysis of the plaster.

Michigan Finished Plasters.

The following analyses were made for the writer by Dr. F. B. Dains of Washburn College, except those of the Powers' Mill and the plaster of Paris made at the Alabastine Mill, which analyses were made in the chemical laboratory of the University of Kansas under the direction of Prof. E. H. S. Bailey.

Alabaster Plaster.

	Per cent.
Silica and insoluble material......................	0.80
Lime oxide (CaO).............................	38.95
Sulphuric anhydride (SO_3)......................	54.67
Water	5.24
	99.66

This analysis would give a probable composition by calculation of:

	Per cent.
Silica	0.80
Lime sulphate..................................	92.95
Lime carbonate................................	1.26
Water	5.24
	100.25

Ivory Plaster of the English Mill.

	Per cent.
Silica and insoluble material	2.13
Lime oxide (CaO)	36.89
Sulphuric anhydride (SO_3)	52.19
Oxide of iron (Fe_2O_3)	0.36
Water	8.55
	100.12

By calculation the analysis would give:

	Per cent.
Silica	2.13
Lime sulphate	88.71
Lime carbonate	0.67
Water	8.55
Iron oxide	0.30
	100.36

Granite Plaster of the English Mill.

	Per cent.
Silica and insoluble material	1.50
Lime oxide (CaO)	37.23
Sulphuric anhydride	52.10
Oxide of iron	trace
Water	8.81
	99.64

By calculation:

	Per cent.
Silica	1.50
Lime sulphate	88.55
Lime carbonate	1.43
Water	8.81
Iron oxide	trace
	100.29

Plasticon Plaster of the Alabastine Mill.

	Per cent.
Silica and insoluble material	1.60
Lime oxide	38.29
Sulphuric anhydride	50.11
Loss, moisture, etc.	9.20
	99.20

By calculation:

	Per cent.
Silica	1.60
Lime sulphate	85.14
Lime carbonate	5.84
Water	6.63
	99.21

This sample showed traces of iron oxide and magnesia oxide.

Alabastine Plaster of the Alabastine Mill.

	Per cent.
Silica	1.38
Lime sulphate	85.91
Lime carbonate	4.48
Water	7.48
Iron and alumina	0.75
	100.00

Granite Plaster of the Powers' Mill.

	Per cent.
Silica	8.64
Lime sulphate	72.45
Lime carbonate	7.96
Water	4.94
Iron and alumina	1.03
Magnesium carbonate	4.98
	100.00

An examination of these analyses shows that the lime sulphate varies from 72.45 per cent in the Power's mill plaster to 92.95 per cent in the Alabaster plaster. The impurities vary from 22.6 to 2.06 per cent. The water percentage varies from 4.94 to 8.81 per cent. The loss of water in the calcining of these plasters is 74, 60, 55 per cent.

These analyses compare favorably with those given of the French plasters and with those from other districts in this country.

MILL NO. 1. GRAND RAPIDS PLASTER COMPANY.

CHAPTER X.

PHYSICAL EXAMINATION OF GYPSUM WALL PLASTER.

§ 1. Introduction.

The physical examination of a Portland cement is regarded as of much more practical value than the chemical analysis. Contracts are made on the basis of such examination and all cements are carefully tested before being accepted for construction work, and the tests are carried along as the work progresses. There has grown out of this demand, a system of testing,[1] which is used with certain variations throughout the world, and is even a subject of legislative and governmental control.

In the case of gypsum cement wall plasters such tests are seldom asked for by the trade, and they are not often made except by the manufacturing companies themselves to secure a control over their product, so they may send out a uniform plaster. Such tests for scientific purposes have been made in this country by the University of Wyoming and by the Iowa Geological Survey. Before the results of either of these departments were published, the writer began work on the same lines and while the results have been partially outlined in the meetings of the Kansas Academy of Science, this is the first published account of the work.

The growing use of plaster in construction, as "staff" etc., will probably lend importance to these tests in the future.

Uniformity in results from cement tests and from gypsum plaster tests are difficult to secure and the personal error as well as the errors of manipulation are leading features in all such tests. Not only do tests on the same material by different persons vary, but even those made on the same material by the same person show variations in results often impossible to explain.

In testing hydraulic cements attempts have been made to establish standards for comparative purposes. This is seen in the work of the German Association of Cement Manufacturers, the French Government Commission in 1891, and in the conferences of the International Association for Testing Materials. In this country there have been no govern-

[1] In the description of the methods of testing cements, the author wishes to give due credit to the articles of R. L. Humphrey in the Journal of Franklin Institute, as well as the various articles in the Proceedings of the American Society of Civil Engineers. See also Mr. Humphrey's paper at the end of Volume VIII of these reports.

ment commissions appointed for this purpose, but in 1885 a committee appointed by the American Society of Civil Engineers reported on a set of rules for cement testing which have served as a standard for the work of testing cements in the U. S. In 1899 another committee was appointed by this society to revise these rules and bring them up to date.

In my own work I have taken the rules of testing Portland cements and adapted them to use with the gypsum plasters.

§ 2. Fineness.

The fineness of grinding of cement is measured by the percentage of residue on No. 50, No. 100, No. 200, sieves having approximately 2,500, 10,000, and 40,000 meshes per square inch. A good cement leaves practically no residue on the No. 50 sieve. According to Humphrey, the sample should be thoroughly dried at a temperature of about 130° F. and the operation can be considered complete when not over 1-10 of 1 per cent passes through after five minutes of continual shaking.

While in Portland cements the fineness of grinding is one of the essential parts of the manufacture, in gypsum plasters for ordinary uses, exceptional fine grinding is not required and the extra cost of such grinding would not justify the work. Taking two plasters which are sold in the Kansas market, and they show the following variation in fineness:

	Per cent.
Not passing through 20 mesh sieve	0.59
Not passing through 40 mesh sieve	8.7
Not passing through 60 mesh sieve	8.1
Not passing through 80 mesh sieve	8.9
Not passing through 100 mesh sieve	15.1
Through 100 mesh sieve	57.4
Lost in sieves	1.21
	100.00

	Per cent.
Not passing through 20 mesh sieve	0.48
Not passing through 40 mesh sieve	5.35
Not passing through 60 mesh sieve	2.21
Not passing through 80 mesh sieve	2.83
Not passing through 100 mesh sieve	3.41
Through 100 mesh sieve	84.56
Lost in sieves	1.16
	100.00

§ 3. Weight.

According to Michaelis a good Portland cement should not weigh over 75 pounds per cubic foot. The specific gravity runs from 2.72 to 3.05. The gypsum rock runs about 2.3 and the calcined plaster has a specific

gravity of 1.81. A cubic foot of plaster of Paris weighs 54.76 pounds determined on Grand Rapids plaster. When set it weighs 103.3 pounds, and with two parts sand to one part plaster a cubic foot weighed 126.2 pounds.

§ 4. Gauging of Plaster.

The preceding tests are applied to the dry material, other tests usually looked upon as more important are applied to the cement or plaster mixed with water. The amount of water used in the mixtures is important in all comparative examinations.

Briquettes made from different proportions of water are found to vary in the tests made. It is then important to determine the percentage of water necessary to make the pats and briquettes of plaster of just the proper consistency for manipulation. The proper mixture has been termed the "normal consistency" of a cement. In many laboratories great care is taken to determine this amount of water.

"At the Charlottenburg testing laboratory in Germany it is the practice to determine the percentage of water to be used, by mixing the cement to a syrupy paste so that it will run from a knife (6 by 1½ inches) in long thin threads without forming lumps. Representing the quantity of the water for this condition by N, then the percentage of water (W) required to produce a normal consistency is obtained from the formula $w = \frac{N+1}{2}$ for neat tests and $w = \frac{N+3}{4}$ for sand tests (1 to 3)" (Humphrey.)

A simple method is also given by Humphrey which he states gives results closely agreeing with the preceding. This consisted of moulding the plaster in a ball and dropping it from a height of one foot. The ball is of the proper consistency when it does not flatten materially or crack in this experiment.

In the present work on gypsum plasters different proportions of water were used until a normal consistency was determined, which would thoroughly moisten the plaster and, on striking with a trowel, would show a moist surface but not bring water to the surface. Different brands of plaster required slightly different percentages of water. In the earth plasters 30 per cent of water represented the average amount to be used, while in the plasters made from the rock, 40 per cent was required. For sand mixtures of earth plaster, 13.4 per cent of water was used.

§ 5. Time of Setting.

The time of the beginning of set and the time of final set in cement and plaster give a classification into rapid and slow setting. Ordinary plaster of Paris sets in a few minutes but by the addition of a retarder the set may be delayed two hours or even twenty-four hours.

The fact that some gypsum plasters run uneven in the time of set is considered by the practical plasterers as an argument against them. The workman uses one day a plaster of certain make which sets as a fairly slow plaster and if the next lot of plaster has a quicker set, he has trouble with the wall unless he uses considerable caution. Certain brands run remarkably uniform in time of setting and stand in high favor with the trade. The cause of this variation is not usually sought for by the manufacturer. The careful chemical examination employed in all Portland cement mills, is seldom made in gypsum mills. The material is placed in the kettles, burned so long, and a certain amount of retarder added, and the finished product is ready for the market. In gypsum rock quarries the quality is usually uniform, but in many of the earth deposits the variations are marked, and careful manipulation is necessary to send out uniform plasters.

The setting time of gypsum plaster may be determined in the same way as in cements. The Vicat needle which carries a given constant weight is brought against the surface of the properly gauged pat of cement or plaster. When this needle under a load of 50 grams failed to sink half way into the pat, the initial set is said to have commenced. When under a load of 300 grams, it fails to sink into the mass the final set is said to have taken place. This method of determination is in common use in the cement laboratories of England and also in this country.

This apparatus, illustrated in Fig. 42, consists of a frame K, bearing the movable rod L, having the cap A at one end, and the piston B, having a circular cross-section of 1 centimeter diameter at the other. The screw F holds the needle in any desired position. The rod carries an indicator which moves over a scale (graduated to centimeters) attached to the frame K. The rod with the piston and cap weighs 300 grams; the paste is held by a conical hard rubber ring, I, 7 centimeters in diameter at base, 4 centimeters high, resting on the glass plate J. 15 centimeters square.

A convenient method with apparatus readily made in any laboratory is by the Gilmore wires. A wire with a flat area of one-twelfth inch and loaded with one-fourth pound is used to determine the initial set. This needle fails to penetrate the plaster when the set has commenced. A second wire with one-twenty-fourth inch area and loaded with one pound will not penetrate the mass when the final set has taken place. These wires were prepared as described and placed in a wooden frame so as to keep them vertical and give a direct pressure on the pat of plaster.

The tests were made on neat cement plaster and carefully timed, the wires were kept clean of all adhering plaster. The time of initial set was determined within a range of very small variation, but the final set was not so readily determined as it is difficult to determine the

exact time of the needle making no impression. In the mixing of gypsum plaster with water it is very difficult to get it thoroughly mixed especially in quick setting plasters, and as a result portions of the pat will be set while other portions are still soft. This result may possibly be explained by inequality in the distribution of the retarder or by some portions of the plaster being more highly calcined than other parts.

In the results of these tests average times of set were selected from a series of tests.

	Initial set.	Final set.
Pure plaster of Paris	7 min.	20 min.
Roman plaster	25 "	3½ hours (retarded.)
O. K. plaster	50 "	4 " "

§ 6. Tensile Strength.

The most popular series of tests on cements are those determining the tensile strength as these are regarded as easy to make and not requiring very expensive apparatus.

Appliances.

In the early days of cement testing, two machines were used, one known as the Grant machine now represented by the Riehle and Olsen machines which are long simple lever machines. The other type smaller and more compact, the Michaelis testing machine, is now found in a modified form in the Fairbanks testing machine. The later machine is perhaps the more popular in this country on account of the ease of handling and compactness, and was used in all the experiments in our laboratory.[1]

The briquettes of cement or plaster are moulded in single or gangue moulds which are held together by clamps in the middle or at the ends of the moulds. They are usually made of brass. The shape of the mould has been modified from time to time, and slightly different forms are now used in different parts of the world. The original square mould of the Grant machine had a one and one-half inch section, but was modified later by Grant so as to have angular ends and this form is still used in England. In the Michaelis machine the briquettes were rounded at the ends and at the center were slight indentations or cunettes to insure the briquette breaking at the center. This form is the standard in Germany and France and has a cross section at the center of five square centimeters.

In the United States the briquettes have slightly angular ends and taper toward the center where the cross section is one inch. Unless the briquettes are carefully adjusted, cross strains are set up and the briquettes tend to break in other places than the center. In the earlier machines the clips of the machine closed tightly on the briquette, allow-

[1] See Vol. VIII, Part 3, of these reports for figures of the different testing machines, also Fig. 40.

ing no room for adjustment. Modern clips are larger and touch the briquette along four lines only, and so are more readily adjusted to remove any cross strains.

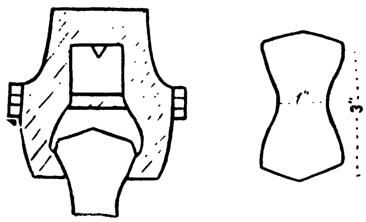


FIG. 36.

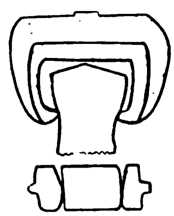
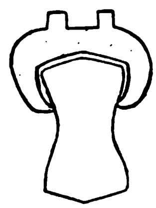
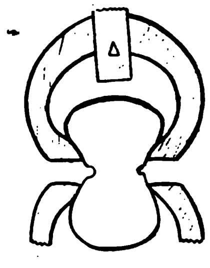




FIG. 37. FIG. 38. FIG. 39.

FIG. 36. Cement Briquette and Clip, used in England.
FIG. 37. Cement Briquette and Clip, used in United States.
FIG. 38. Cement Briquette and Clip, used in United States.
FIG. 39. Cement Briquette and Clip, used in Germany and France.

Mixing.

The cement or plaster is thoroughly mixed or gauged with the proper amount of water, on a non-absorbing surface like plate glass or marble. The German method is to mix a slow setting cement three minutes and a quick setting cement one minute. Plaster being usually quick setting should be mixed as quickly as possible. Mechanical mixing machines like the Russell jig and Faija mixer are not used in very many American laboratories. The work is carried on in a room of uniform temperature if possible.

When the plaster is thoroughly mixed it is pressed into the mould by hand and gently forced into place. The surface is then struck off smooth with the trowel and mould turned over and the other side smoothed off if necessary. After a few hours the briquettes can be removed and after being carefully numbered are laid aside for the breaking tests.

In the experiments of the Washburn College laboratory, with quick setting plasters, one briquette was moulded at a time, using 3½ ounces (99.2 grams) and 40 cc. of water representing the 40 per cent mixture. In the slow setting plasters 19 ounces (538.46 grams) are used with

about 165 cc. of water and five briquettes are made, a 30 per cent mixture. The proportion of water varied somewhat with the plaster used in the experiments. In the Kansas plasters for a stiff mixture, the water percentage varied from 26.3 per cent to 40 per cent for neat briquettes (without sand); and in sand mixtures (2 to 1) the water percentage varied from 12 to 14, and proportions were about the same in the Michigan plasters. Nearly 600 briquettes were made and broken at intervals of 24 hours, 7 days, 30 days, 6 months, and 1 year.

The briquettes for the long time test were set on edge on glass and kept in a room of fairly uniform temperature until broken. The sand used was ordinary Kansas river sand screened through a sieve (No. 20) of 400 meshes and held by a screen (No. 40) of 1,600 mesh, and carefully dried. The sand mixtures were two parts of sand to one of plaster. The quick setting plasters required the higher water percentage in mixing and the slow setting, the lower percentage.

FIG. 40. Fairbanks testing machine.

Breaking.

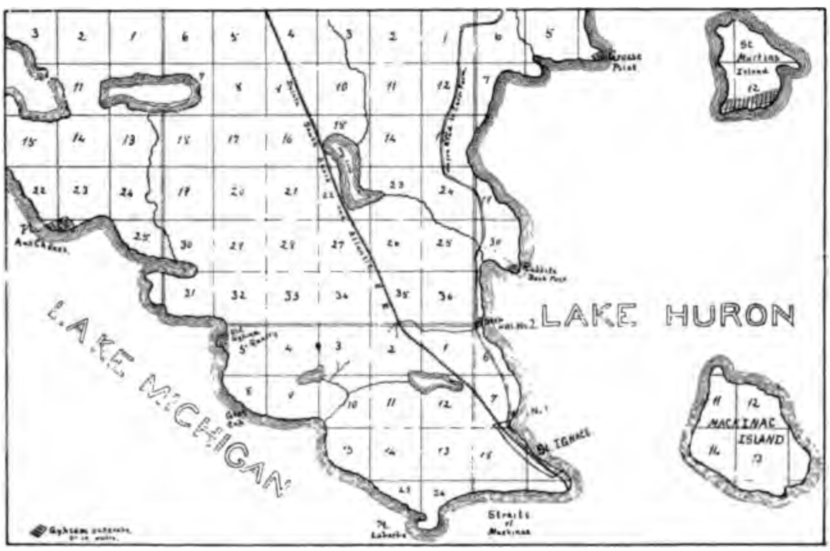
The briquettes were broken in a Fairbanks machine. In this portion of the work care must be taken to properly center the briquettes and avoid cross strains with resulting cross breaks away from the center The presence of air bubbles and incipient cracks will sometimes cause the diagonal breaks even in the most careful manipulation. In the briquettes of high strength the bucket was always loaded with a light weight and the shot allowed to flow in a small and uniform stream.

Tables.

The tests of the Michigan plasters were made in the laboratory under my supervision by two advanced students, Mr. Elmer Schultz and Mr. John Worsley, and their results were accepted as thesis work for their degrees, by Washburn College.

TENSILE STRENGTH OF GYPSUM WALL PLASTER.

Kind of plaster.	24 hours.		One week.		One month.		Six months.		One year.	
	Pounds.	Average.	Pounds.	Average.	Pounds.	Average.	Pounds.	Average.	Pounds.	Average.
Roman (Kansas). Neat	215 280 282 298 210	255	380 390 380 395	386	550 543 567 492	553	402 458 poor poor	430	466 305 340	370
Roman (Kansas). Two parts sand	130 112 111	117	370 340 382 312	351	398 365 360 375	375	328 310 425	364	281 292 268 270	278
O. K. (Oklahoma). Neat	202 270 215	229	545 555 376 365	460	594 465 476 563	525	515 505 543 610	543	421 390 494 469	44[illegible]
O. K. (Oklahoma). Two parts sand	100 90 92 82	91	372 340 280 280	318	410 410 435 365	410	378 368 397 322	366	288 289 284 278 324	293
Keene's Cement (Kansas). Neat	240 243 235 159	220	430 403 402 472	426	368 440 517 368	423	356 440 490 500	447	493 337 515 497	461
Keene's Cement (Kansas). Two parts sand	40 47 39 44	43	180 202 178 195	189	223 190 126 92	180	236 228 248	237	230 263 244 214 249 204	234
Satin Spar (Kansas). Plaster of Paris. Neat	297 270 270 254	273	526 325 326 483	415	585 534 667	595	553 515 635 786	622	495 407 407 poor	436
Crystal Rock (Kansas). Two parts sand	140 144 148	144	480 525 510 491	502	450 512 533	498	423 423 444 340	408	380 362 405 399	387



SKETCH MAP OF ST. IGNACE AREA.

A.

A.

B.

C.

C

D

E

TENSILE STRENGTH OF MICHIGAN GYPSUM WALL PLASTERS.

Kind of plaster.	24 hours.		One week		One month.		Six months.	
	Pounds.	Average.	Pounds.	Average.	Pounds	Average.	Pounds.	Average.
A. Made at Grand Rapids. Neat	215 215 200 238	217	404 385 447 467	422	....	....	405 445 390 403	411
A. Same plaster. Two parts sand	106 91 100	99	372 340 360	324	242 269 222 218	210	302 295 288 347	308
B. Made at Grand Rapids. Neat	....	....	468 508 453 430	465	562 477 500 462	500	495 454 496 319	441
C. Made at Grand Rapids	228 273 278 238	254	658 618	638	650 617 540 524	575	*555 *736 *731 *696	680
C. Same plaster. Two parts sand	....	....	400 420 452 454	431	257 266 252 266	260	*353 *311 *321	328
D. Made at Grand Rapids. Neat	349 345 311 342	336	498 510 387 320	429	538 549 407 350	461	†503 †410 †478 †312	426
D. Same plaster. Two parts sand	117 116 143	125	387 398 473 391	412	207 370 317 314	302	410 261 359 347	344

* Three months.
† Two months.

TENSILE STRENGTH OF OLD GYPSUM WALL PLASTER.

Kind of plaster.	One month. Pounds.	One month. Average.	Five months. Pounds.	Five months. Average.	Two months. Pounds.	Two months. Average.
O. K. (Oklahoma). One year old plaster. Neat	......	......	372	458	324	277
	......	......	543		220	
	......	......	458		242	
	......	......	478		340	
	......	......	440		294	
	......	......	......		245	
Roman (Kansas). One year old plaster. Neat	252	337	129	150	383	359
	400		147		410	
	359		168		342	
	......		158		300	
Plaster of Paris. (Kansas). One year old plaster. Neat	528	536	......	......	......	......
	607		......	......	......	......
	494		......	......	......	......
	507		......	......	......	......
	583		......	......	......	......
	500		......	......	......	......
Roman (Kansas). One year old plaster. Two parts sand	......	......	195	186	263	298
	......	......	100		262	
	......	......	240		352	
	......	......	210		316	

Discussion of Results.

In the gypsum earth plasters of Kansas the maximum strength appears to be reached in one month and then they decline in six months and one year. This decline is more marked in the neat plaster than in the sanded plaster. These plasters are represented in table I by the Roman and O. K.

The rock plasters represented by Keenes and Satin Spar show their greatest strength in six months. The Crystal Rock also a rock plaster gave its greatest strength in one week. The greatest strength recorded was of plaster of Paris in six months when one briquette broke at 786 pounds. In sanded mixtures the rock plaster stood higher tests than the earth plasters.

Even a hasty examination of these tables shows the variation in results of the same plaster tested in the same length of time by the same person who endeavored to secure as uniform manipulation as possible. It has been urged by some of the practical operators that only the highest tests should be used in judging plaster or cement, because the plaster will have a certain highest strength which cannot be increased by the person making the test, but which can be lowered, and in the mixing of the plaster the workman is more apt to lower the strength than to increase it. The results, however, as given will probably agree more closely with the average results of the plasterer in his work, who will not always if ever secure this greatest strength of the plaster.

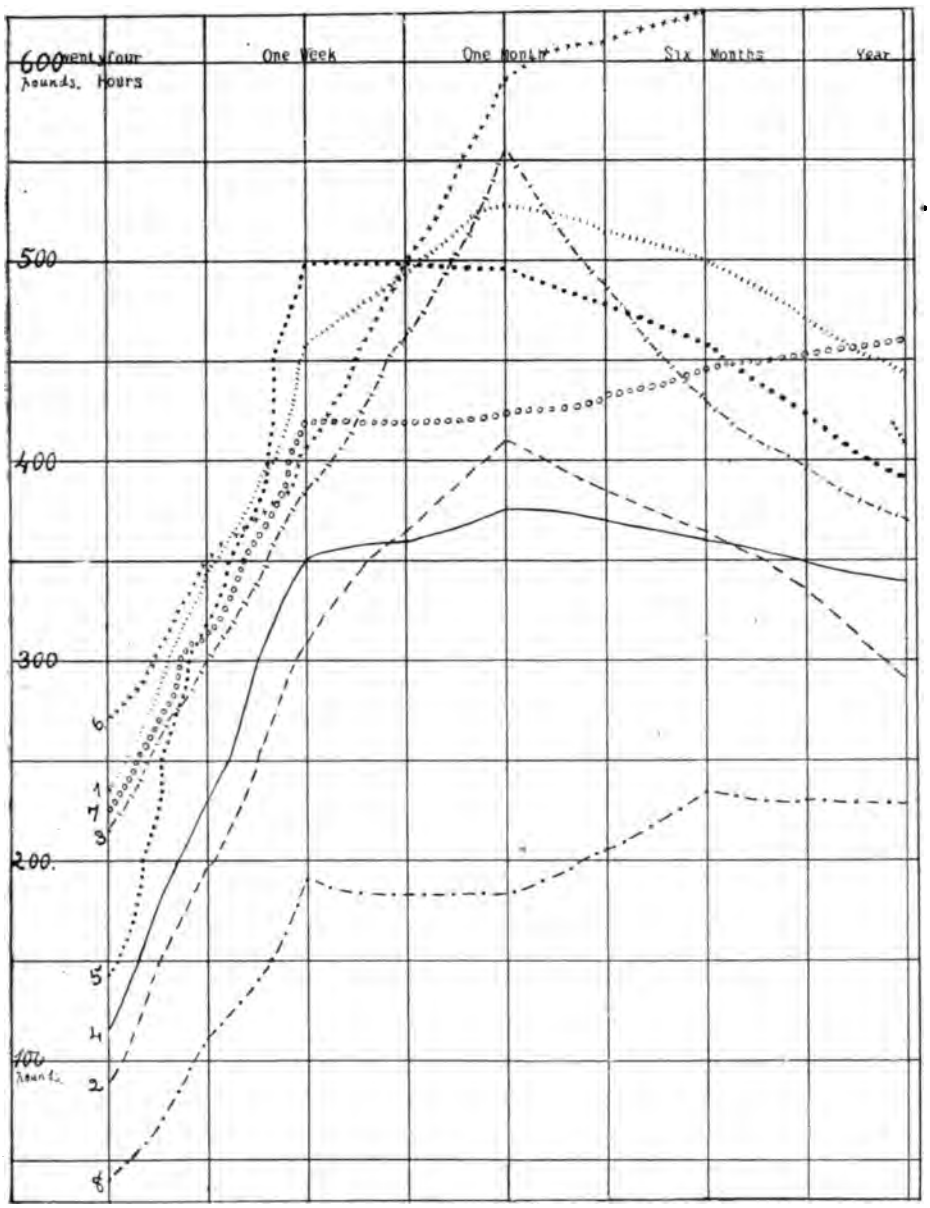


FIG. 41. Chart of tensile strength of gypsum plasters, one day, one week, one month, six months and a year, after setting.

1. O. K. Cement Wall Plaster (neat).
2. O. K. Cement Wall Plaster (2 parts sand).
3. Roman Cement Wall Plaster (neat).
4. Roman Cement Wall Plaster (2 parts sand).
5. Crystal rock Cement Wall Plaster (2 parts sand).
6. Satin spar Cement Wall Plaster (neat).
7. Keenes Cement Plaster (neat).
8. Keenes Cement Plaster (2 parts sand).

It must be clearly kept in mind that the lowest of these tensile strengths is far greater than any strain that will ever be applied to a wall. So in practical work these are all good plasters, and the ease of working, and the uniform results of different ton lots will be of more value in determining the superiority of one brand over another. Such tests as are given in these tables are valuable for comparative purposes.

Why the strength should fall after one or six months is an unsettled problem. The amount of retarder added is so small that we can hardly look to that for an explanation, though it may have some effect on the crystal network and changes in the retarder in time may effect the strength of this network. The real explanation lies hidden in the adjustment of crystals in the network and belongs to the obscure subject of crystallization, its causes and steps in its progress. It is evident that in some of these plasters the early changes in crystal formation are slower than in others as a marked variation is seen in 24 hours which disappears later. This is especially true of the sanded plasters.

The Michigan plasters are all made from rock, as no gypsum earth deposits are known in the state. The greatest increase in strength of these plasters from 24 hours to one month as is also true of the Kansas plasters, shows that the final set as determined by the needles does not represent the complete setting of the plaster. The changes of crystallization which we call the set are going along rapidly at first then more slowly for one month and in some cases six months, and the re-adjustment of the network of crystals would seem in some of these plasters to be going on for a year after they are mixed with the water.

A number of the Michigan plasters seem to reach their maximum strength in one week and decline in strength in one month. The greatest strength recorded was of a briquette broken at 736 pounds after three months. These results of tests do not show any great variations from the same kinds of Kansas plasters.

Tests on Old Plasters.

The statement is often made that gypsum plasters cannot be kept long without losing their strength and that in a few months they are of low strength or even worthless. Several sacks of plaster were left in a room near the laboratory for over a year. These sacks were open and the room was damp in the spring, and not heated in the winter, so the plasters were exposed to a varying temperature from the hot summer to the cold winter. Briquettes were made from these samples and broken giving the results shown in table III. These plasters were from the same sacks which furnished the material used for the briquettes shown in table I.

Comparing the results of the two tables, of fresh plaster and plaster

exposed one year, it is found that the O. K. plaster in 5 months has decreased in strength from near 543 pounds to 458. The plaster of Paris in one month from 595 to 536 pounds. The Roman in one month from 553 to 337, and in five months from near 430 to 150 pounds. This last brand is the only one which shows any serious effect of the exposure. These plasters under as bad conditions of exposure as would ordinarily be found show decrease of strength, but they are still after one year's exposure good plasters.

To test frost effects on these gypsum plasters, a number of briquettes were made and as soon as set were placed out of doors in the open air for one week with the temperature below freezing, and the briquettes broke from 352 to 793 pounds with an average of 500 pounds, showing practically no effect on the strength for that time.

Some Low Tests.

At some of the mills there is a tendency to draw the plaster from the kettles before the second boiling, and some of the operators have claimed that such plaster is just as good as any other. If this claim was true it would give the advantage of calcining plaster with less fuel and save much time so adding to the capacity of the plant. Among the various sacks of plaster brought from Michigan, two sacks were tested, one of which showed by chemical analysis a high percentage of water and evidently it had been drawn from the kettle too soon. The plaster when set would break when taking it from the mould and would not test as high as 100 pounds when the greatest care was taken with the briquettes.

The other brand showed too low a water percentage and the tests showed it had a very low tensile strength. It was tested neat and after 60 days gave the following results:

91 pounds	
156 pounds	
101 pounds	
232 pounds	Average 150 pounds.
186 pounds	
145 pounds	
139 pounds	

Another sack of good plaster from the same mill made at another time gave, when tested in the same way and after the same length of time:

503 pounds	
410 pounds	Average 426 pounds.
478 pounds	
312 pounds	

These results seem to show that of the two evils, under-burning and over-burning, the former is the greater. These plasters should reach in

60 days at least 500 pounds tensile strength,. as they are made from good rock and with good appliances for calcining. These tests are useful in showing that poor plaster can be made from the best material by faulty manipulation. It may be due to cheap and inexperienced calciners or to careless ones. This trouble is found in all plaster fields and I have found similar poor plasters in other districts. The tests were carried out with plasters from nearly all the Michigan mills, and these two sacks were the only poor plasters found, and further, the mills that made these poor plasters are sending out some of the finest grades of Michigan plaster.

§ 7. Comparison of Physical Tests with Chemical Analyses.

It was thought that a careful comparison of physical tests with the chemical analysis might throw some light on the effects of certain ingredients in the rock on the strength of the plaster made from the rock. When the results of these tests are compared, a variation is found in the tests on plasters at different mills made from rock of practically the same chemical composition. The time of calcining and the amount of heat used as well as many other factors vary and so produce variations in results which obscure the effects of the rock impurities.

The earth plasters with their impurities of clay, silica, and lime, set slower than the rock plasters and usually show a little lower tensile strength, especially when mixed with sand.

Another method was used to determine the effects of these impurities. Pure plaster of Paris was tested and then varying proportions of powdered limestone were added, also different proportions of powdered clay. Briquettes were made from these mixtures and broken after 30 days.

Per cent of lime.	Carbonate of lime mixture. Lbs.	Carbonate of lime mixture. Average.	Per cent of clay.	Clay mixture. Lbs.	Clay mixture. Average.	Pure plaster of Paris. Lbs.	Pure plaster of Paris. Average.
	390					585	
1.	392	352				534	595
	275					667	
	360			poor			
2.	248	310	2.	248	288		
	323			328			
	286			262			
3.	348		4.	350	302		
	494			293			
	331						
6.	321	328					
	332						
	375			357			
8.	389	381	8.	340	328		
	379			287			
	345			342			
10.	285	291	10.	217	283		
	244			290			

The addition of the lime and clay had a tendency to cause the briquettes to swell and so make them difficult to place in the clips of the machine. This binding of the briquettes causes them to break away from the center in a number of cases. The addition of these impurities lowered the strength, but the different proportions did not change the results materially until the 10 per cent mixture was reached. The setting time was but little altered.

Another line of experimental work was tried by mixing the ground clay with ground gypsum rock and calcining the mixture as follows: One pound of ground clay was mixed with seven pounds of gypsum flour and placed in a kettle heated to 250° F. (120° C.) and heated for a half hour to a temperature of 266° F. (130° C.) when the boiling ceased. The mixture was heated 15 minutes longer and the temperature reached 386° F. (196° C.) and then the whole mixture was withdrawn having been heated about one hour. The color of the finished plaster was reddish. It set in one hour and the briquettes in one week had a tensile strength of 500 to 585 pounds. A one-fourth mixture gave a reddish plaster which set in one and one-half hours.

The adding of the clay impurity before calcining the rock increased the tensile strength and formed a slow setting plaster. In sand mixtures, however, the plaster showed a very low tensile strength similar to the Keene's cement tests as given in table I in an earlier part of this chapter. Such cements are used neat or if mixed with sand have lime added to them. The specifications with the use of Keene's cement state as imperative that for sand mixtures three bushels of slaked lime must be added for each 100 square yards of surface. The tests given were on the cement without any addition of lime.

The analysis of the mixture of one part of clay to seven parts of gypsum after calcining is given below with analysis of plaster made from gypsum rock and gypsum earth.

	Mixture 7 to 1.	Earth Plaster.	Rock Plaster.
Silica and insoluble material......	12.30	12.02	1.20
Iron and alumina..................	0.78	0.44	0.20
Lime carbonate....................	0.07	14.39	1.68
Lime sulphate.....................	83.48	68.36	89.42
Water.............................	2.80	4.98	6.82
	99.43	100.19	99.32

The mixture agrees closely with the earth plaster in its percentage of silica, but is lower in lime carbonate. In percentage of lime sulphate the mixture stands between the earth and rock plasters. It was evidently burned at a higher temperature than the other plasters as shown in the water percentage, but the high strength of the plaster would argue against this percentage of water being a defect in the plaster.

The clay when added to the calcined plaster has little effect, but when added before calcining it has the effect of a retarder without lowering the strength of the plaster. The experiments would suggest that the clay in the earth plaster acts as a retarder, but that the full effect of this impurity is only seen when the plaster is heated to a high temperature.

§ 8. Compression Tests.

Compression tests on cement are also held in high favor by many experts. On account of the expense of the machinery for this work and the difficulties in making the tests, the compression tests are not often made. They are usually made on two inch cubes. Such tests have been made on gypsum plasters by the Wyoming Geological Survey.

A series of compression tests were made with the same mixtures and the same time of exposure as in the tensile tests. The plasters used were mainly Kansas products and they were moulded in prisms of the size 2 by 2 by 4 inches, and the pressure was applied to the ends of the prisms in a hydraulic compression machine at the Sante Fé shops at Topeka. The results are given below:

	One week.		One month.		Six months.	
Plaster.	Lbs.	Av.	Lbs.	Av.	Lbs.	Av.
Roman Neat	7600 7850 7300	7583	7250 7400 8000	7550	11050 9450 7820	9440
Roman Two parts sand	5200 5000 4000	4733	4100 4100 6300	4833	4950 4720 5760	5143
O. K. Neat	5600 7300 8800 7500	7300	14250 12475 11175	12966	10000 11830 10950	10926
O. K. Two parts sand	6250 7125 7125 7125	7125	8000 8200 7550	7916	4700 6500 6050	5750
Crystal Rock Neat	8000 6000	7000	7830 5350	6590		

The next table shows the relation of the compression tests per square inch to the tensile strength per square inch, being as many times the tensile strength as is indicated by the figures.

Plaster.	One week.	One month.	Six months.
Roman, neat	4.8	3.2	5.5
Roman, two parts sand	3.3	3.2	3.5
O. K., neat	7.9	6.1	5.0
O. K., two parts sand	19.5	4.1	3.1

§ 9. Absorption Tests and Effect on Strength.

Briquettes of gypsum plaster were made in the moulds and after dry-

A. OLD LIME KILNS ON SLOPE OF RABBIT'S BACK.

B. RABBIT'S BACK RIDGE, NEAR ST. IGNACE.

ing were placed in water, then in air and allowed to dry, and then placed again in the water, and after drying were broken.

Three briquettes of neat O. K. plaster made in Oklahoma showed an average weight after 24 hours in the air of 118.6 grams. These were placed in water for 72 hours and gained 4.8 grams in weight or a gain of 4 per cent. This does not represent the real gain of water by absorption, as part of the material of the briquette went into solution, as shown by their weight after exposure in the air of the same room for a week, when they showed an average weight of 112.6 grams, which compared with their weight when removed from the water (123.39 grams) shows a gain through absorbed water of 10.79 grams or 9.5 per cent. These briquettes were again placed in water for 60 hours, then left in the air for 12 days. They were broken 32 days from the time of mixing and showed a maximum tensile strength of 522 pounds and an average of 466 pounds. The same cement tested in the ordinary way in 30 days gave a maximum strength of 594 pounds with an average of 525 pounds.

Roman cement plaster made in Kansas was tried in the same way. The neat briquettes had an average weight of 111.14 grams and after three days in the water showed an average weight of 118.1 grams, or a gain of 6.96 grams or 6.2 per cent. These were then exposed in air for five days and placed in water six and one-half days and left in the open air again fourteen days. Thirty days after the first mixing the briquettes were broken and showed a maximum strength of 587 pounds and an average of 496 pounds. The Roman plaster treated in the ordinary way showed a maximum of 567 pounds and an average of 553 pounds.

Keene's cement plaster made as a special preparation of hard plaster with an average weight of briquettes of 123 grams, after three days in water weighed 129.6 grams, or a gain of 6.6 grams or 5.1 per cent, and treated in the same way as the Roman gave a maximum test of 465 pounds and an average of 445 pounds. Tested in the ordinary way the maximum tensile strength was 517 pounds and average was 423 pounds.

The loss in strength shown in O. K. plaster in this treatment was 59 pounds; in Roman, 57 pounds; while in the special brand of Keene's cement, an increase was shown, probably due to some error in manipulation of the tests. These water tests show that standard gypsum plasters are not injured to any great extent by such soaking. This accords with practical experience for often gypsum plaster walls wet from leaking roofs dry out and appear to be as strong as ever.

§ 10. Tensile Strength of Gypsum Plasters and Lime Plasters.

An effort was made to secure the tensile strength of ordinary lime plaster moulded in Fairbanks moulds and broken in the testing machine.

The lime was carefully slaked and mixed with two parts of sand. The briquettes so made showed a tendency to crack and many of the experiments were failures on this account.

Mixture.	One week. Lbs.	Av.	One month. Lbs.	Av.	Six months. Lbs.	Av.
Lime plaster Two parts sand.	24 16 18	19	23 25 32	27	38 42 53 68	50

These results show a very low tensile strength for the lime when used in these small masses. The addition of hair to the lime as is done in the ordinary use of lime plaster and the larger quantities give better results, than would be indicated by these tests. Lime plaster has a good tensile strength on the wall, but cannot equal the hard gypsum plasters. The effect of dampness, jars, fire, etc., are much more destructive to lime walls than to gypsum plaster walls. The durability of the gypsum plaster wall is certainly much greater than is the case of the lime wall. The tensile strength of gypsum plaster walls can be increased by the addition of fibre and especially by the use of wood fibre. It was the intention to make a series of tests of such fibred plasters, but it is difficult to secure uniform results with ordinary fibred plasters when used in small space of a briquette mould as the fibres are long enough to get in the way and leave air bubbles in the plaster. I was unable at the time these tests were made to secure samples of wood fibred plaster. In these plasters the wood fibre is small and would not cause the same trouble in the work that the longer fibre did.

§ 11. Adhesion Tests.

Adhesion tests have been made at times on Portland cements, but they are not common. It is found that such cement will adhere to ground glass better than to brick or stone and adheres but poorly to a wood surface. A convenient method of applying the test is to cement two stones or bricks crosswise at right angles and determine the weight necessary to pull them apart.[1]

In tests of gypsum plasters made by the Iowa Survey, pieces of paving brick were ground on an emery wheel so as to give approximately one inch cubes. One face of the cube was carefully ground to give a cross section on one square inch. These pieces were placed in cement moulds with the true one inch surface at the center of the mould. The other half of the mould was filled with plaster and the vacant place around the piece of brick was filled with neat Portland cement mortar. When these briquettes were broken they showed the adhesive strength of the plaster to be only a fraction of the tensile strength.

[1] See article on cement tests, Vol. IX, Part III, of these reports.

In the present work a considerable number of adhesion tests were made by selecting briquettes which had been broken at the center and were fairly smooth in section. These were thoroughly wet with water and placed in the moulds and the remaining half was filled with plaster. The results of these tests while perhaps not valuable for scientific comparisons with tests made in other laboratories by different methods, yet throw light on the adhesive character of gypsum plasters when spread over walls with another coat partially dry, or in repair work on old walls. When the old plaster in these experiments was not wet, there was scarcely any trace of adhesion, which shows that in such repair work the wall should be thoroughly wet before the new plaster is added.

This method used on the Iowa Survey gave adhesion tests which seldom reached 100 pounds in four weeks and most of the tests showed less than 50 pounds. The method used in the present work showed higher results, and results that were in the main no more variable than in tensile tests.

Plaster.	One day. Lbs.	One day. Av.	One week. Lbs.	One week. Av.	One month. Lbs.	One month. Av.	Two months. Lbs.	Two months. Av.	Three months. Lbs.	Three months. Av.
Granite. Neat.	54, 49, 20, 69	48	96, 142, 212	150	116, 36, 98	83			159, 217, 295, 382, 275, 291, 321, 247	273
Granite. Two parts sand.	50, 37, 45, 67	50	94, 62, 49	68	133, 116, 166	138	328, 232, 110, 287, 106, 167, 230, 146, 318	214	237, 110, 195	181

The relation of the adhesive strength to the tensile is shown in the following table, the tensile strength being as many the adhesive as is indicated by the figures. The three months adhesive tests are compared with the six months tensile tests.

Plaster.	One day.	One week.	One month.	Three months to six months tensile.
Granite. Neat.............	4.5	2.8	Not determined.	1.5
Granite. Two parts sand.............	2.0	4.7	1.5	7.1

§ 12. Specific Gravity.

No tests were made for the determination of the specific gravity of these plasters. Experiments could be made along this line which would

without doubt produce interesting results. It was hoped earlier in the work that opportunity would be found to make these determinations. According to Humphrey, LeChatelier's method is the most convenient to use in determining the specific gravity of cements, and it could well be used with the gypsum plasters, and his description is here given.

The apparatus consists of a flask D of 120 cc. capacity (see Fig. 42), the neck of which is about 20 centimeters long. In the middle of this neck is a bulb C, above and below which are two marks engraved on the neck, the volume between these marks E and F being exactly 20 cc. Above the bulb the neck is graduated into one-tenth cc. The neck has a diameter of nine mm. Benzine free from water and being neither very volatile nor hygroscopic is used in making the determinations.

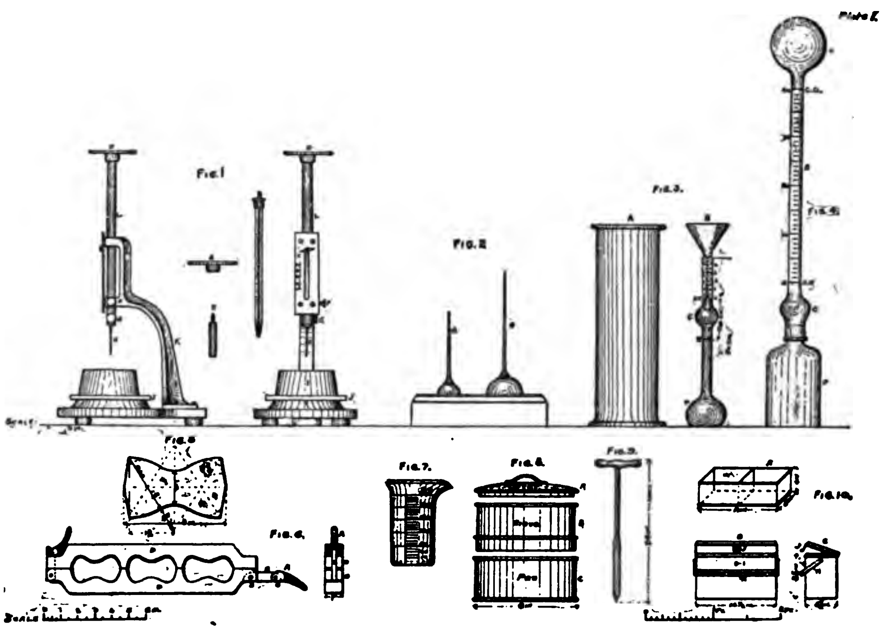


FIG. 42. Modern form of Vicat needle and other testing apparatus for Portland Cement. Upper row left to right, Vicat needles, Gilmore wires, specific gravity apparatus. Lower row, moulds, graduate, sieves.

The specific gravity can be determined in two ways:

1. The flask is filled with benzine to the lower mark E, and 64 grams of powder are weighed out and carefully introduced into the flask by the aid of the funnel B. The stem of this funnel descends into the neck of the flask to a point a short distance below the upper mark. The cement cannot stick to the sides of the neck and obstruct the passage. As the level of the benzine approaches the upper mark, the powder is introduced carefully and in small quantities at a time, until the upper mark is reached. The differences between the weight of the cement

remaining and the weight of the original quantity (64 grams) is the volume which has displaced 20 cc. of the liquid.

2. The whole quantity of the cement is introduced and the level of the benzine rises to some division of the graduated neck. The reading plus 20 cc. is the volume displaced by 64 grams of cement.

The specific gravity is then obtained from the formula:

$$\text{Specific gravity} = \frac{\text{weight in air}}{\text{displaced weight}}$$

or

loss of weight in liquid.

During the operation the flask is kept immersed in water in a jar A, in order to avoid any possible error due to variation in the temperature of the benzine. The cement in falling through the long neck completely frees itself from all air bubbles. The results are said to agree within .02.

§ 13. Influence of Sand on Plaster.

The addition of sand lowers the tensile strength of the plaster as is shown in the tables of the tests already given. In ordinary lime plasters sand is necessary to increase the adhesive properties of the plaster, and sand is said to increase the adhesion of Portland cements. In the gypsum plasters, the tests of adhesion given show that the addition of sand decreases the adhesion of plaster as well as the tensile strength. These results would indicate that sand is not needed in gypsum plasters to give them tensile or adhesive strength. The addition of sand to these plasters makes them cheaper as a sack of plaster with the addition of the proper amount of sand will cover a greater surface, and without injuring the strength in any practical degree.

Another important influence on the addition of the sand is in making the plaster easier to work. Pure gypsum plaster mixed with water is more or less sticky and tends to roll up into lumps. The addition of sand overcomes this trouble. The advantages of sand mixtures are not in the strength and probably not in the duration of the wall, but rather in convenience to the workman, and therefore in the better character of the wall for this same reason, and in the reduction of the cost. This latter reason sometimes tempts the workman to add an excess of sand and so to make a weaker wall. Crumbling gypsum plaster walls that are sometimes reported are either due to improper burning, or to too much sand added, or again to use of old partially set plaster left in the mortar boxes.

CHAPTER XI.

ORIGIN OF GYPSUM.

§ 1. Deposition by Action of Sulphur Springs and Volcanic Agencies.

Various theories have been advanced to explain the origin of gypsum in various parts of the world. In order to arrive at a satisfactory explanation of the origin of the gypsum deposits of Michigan, a brief resumè of these theories will be given in this chapter.[1]

Gypsum is deposited directly by some thermal springs as in Iceland[1], where it is formed by the decomposition of volcanic tufa by acids dissolved in water. The sulphurous acids become oxidized to sulphuric, and thus convert the carbonates, especially of the lime and magnesia, into sulphates. Through evaporation the sulphate of lime is deposited, forming layers of fibrous and selenitic gypsum.

Small gypsum deposits are found around the fumaroles[2] of the craters and lava streams in Hawaii where sulphurous acid is converted into sulphuric, and attacks rocks which contain lime. Gypsum is found in the form of acicular crystals associated with sulphur in the craters in New South Wales.[3] The gypsum concretions of the Hartz are regarded as due to the action of sulphur vapors on lime rock. According to Lapparent[4] the large deposits of gypsum and anhydrite at Montiers, Bourg-Saint-Maurice, in the western Alps and Switzerland are due to the transformation of lime through sulphur reaction.

Dana[5] explains the origin of a portion of the New York gypsum as a secondary mineral due to the alteration of the limestone by action of sulphuric acid. The acid comes from sulphur springs by the oxidation of the sulphuretted hydrogen. Such springs are found in New York especially near Salina, and Syracuse, also at Byron in Genesee County. The layers of shale sometimes pass through the gypsum, and the gypsum is connected with the overlying waterlime beds as shown in Figure 43 after Hall taken from Dana's text book.

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[1] See also Vol. V. of these reports, the introduction to Part 2.
[1] Bunsen in Annalen der Chem. 1847.
[2] Iowa Geol. Survey, Vol. XII, p. 116; 1902.
[3] Minerals of New South Wales, p. 164; 1888.
[4] Lapparent Geologie, p. 1026.
[5] Dana Manual of Geology, pp. 554-555; 1895.
See also report No. 64, U. S. Depart. of Agriculture. Division of soils, p. 54, gypsum formed from limestone in Texas.
Personally I am inclined to think that in most cases the genesis is inverse, the sulphuretted hydrogen being the product of carbonated water, organic matter and gypsum. L.

According to Lyell[1], the thermal waters of Aix in Savoy in passing through the strata of Jurassic limestone turn them into gypsum, also the springs of Baden near Vienna deposit a fine powder composed of a mixture of gypsum, sulphur, and "muriate of lime." In the Andes at the Puenta del Inca, a thermal spring contains a large proportion of gypsum and carbonate of lime.

Mr. R. S. Sherwin[2] who has studied the gypsum deposits of Oklahoma regards the massive gypsum of this section as due to the alteration of limestone by the water of sulphur springs.

Dawson[3], following Lyell, explained the origin of the gypsum of Nova Scotia as follows:—First, there was an accumulation of numerous thin layers of limestone, either so rapidly or at so great a depth that organic

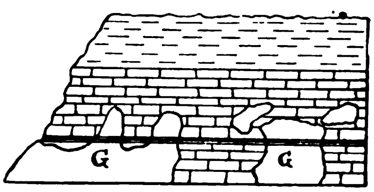

FIG. 43. Limestone altered in part to gypsum, after Dana.

remains were not included in any but the upper layers. Second, there was an introduction of sulphuric acid, in solution or in vapor, which was a product of volcanic action. Then for a long time the acid waters acted upon the calcareous material without any interruption from mechanical detritus. The limestone and calcareous matter are changed to the sulphate, and gypsum of good quality accumulates in considerable thickness.

§ 2. Hunt's Chemical Theory of Gypsum Formation.

Hunt's[2] chemical theory of the formation of gypsum is somewhat complex, but he believed it applied to a large part of the gypsum deposits of marine and fresh-water origin. In his own words the theory is as follows:—

"1. The action of solutions of bicarbonate of soda upon sea water separates, in the first place, the whole of the lime in the form of carbonate, and then gives rise to a solution of bicarbonate of magnesia, which, by evaporation, deposits hydrous magnesian carbonate.

"2. The addition of solutions of bicarbonate of lime to sulphate of soda or sulphate of magnesia gives rise to bicarbonates of these bases, together with sulphate of lime, which later may be thrown down by alcohol. By the evaporation of a solution containing bicarbonate of

[1] Lyell Principles of Geology, p. 245.
[2] Transactions Kans. Acad. Science, Vol. XVIII, p. 85.
[3] "Origin of Gypsum at Plaister Cove, Nova Scotia," Quarterly Journal Geological Society, Vol. V, p. 339, 1849.
[2] Quarterly Jour. Geol. Soc. Vol. 16, p. 154, 1859. Chem. and Geol. Essays, pp. 80-92, 1878.

magnesia and sulphate of lime, either with or without sea salt, gypsum and hydrous carbonate of magnesia are successively deposited.

"3. When the hydrous carbonate of magnesia is heated alone, under pressure, it is converted into magnesite; but if carbonate of lime be present, a double salt is formed, which is dolomite.

"4. Solutions of bicarbonate of magnesia decompose chloride of calcium, and, when deprived of their excess of carbonic acid by evaporation, even solutions of gypsum, with separation of carbonate of lime.

"5. Dolomites, magnesites, and magnesian marls have had their origin in sediments of magnesian carbonate formed by the evaporation of solutions of bicarbonate of magnesia. These solutions have been produced either by the action of bicarbonate of lime upon solutions of sulphate of magnesia, in which case gypsum is a subsidiary product, or by the decomposition of solutions of sulphate or chloride of magnesium by the waters of the rivers or springs containing bicarbonate of soda. The subsequent action of heat upon such magnesian sediments, either alone or mingled with carbonate of lime, has changed them into magnesite or dolomite."

§ 3. Deposition of Gypsum Through Action of Pyrites Upon Carbonate of Lime.

Pyrites or iron sulphide decomposing in clays may change the carbonate of lime into sulphate of lime, and so form gypsum, usually in small amounts and scattered through the clay.

These crystals are found in the coal measure clays of Kansas (see Vol. V, Kans. Survey, p. 73) near the surface, and in size varying from microscopic crystals up to an inch in diameter. The neighboring shales are heavily charged with pyrite, which decomposes forming iron sulphate, which is carried in solution and acts on the limestone and shales. Gypsum produced in this way often forms very perfect crystals, but it is not of economic importance.

§ 4. Gypsum Deposited in Rivers.

Rivers may in some instances carry high percentage of sulphate of lime and so deposit gypsum at their mouths or in the basins into which they empty. Lyell in his Principles of Geology (p. 247) cites the river in Sicily known as La Fiume Salso, as an example of this method of origin.

§ 5. Secretion of Gypsum by Animals.

In the cruise of the Challenger[1], M. Buchanan found the Bathybius forming a sulphate of lime deposit. This unicellular animal belongs to the lowest group of animal life and forms slimy masses on the bottom of the sea. Many believe it is not an animal, but merely a deposition of lime salts in the water.

[1] Lapparent Geologie, p. 135.

§ 6. Gypsum Formed from Anhydrite.

Anhydrite ($CaSO_4$) on taking up two molecules of water forms gypsum, and causes an increase in volume of 33%. According to Lapparent the force exerted by this change is four times as great as that of water freezing. This change on a small scale is found in many places, but in the Hartz mountains, according to Gary, the gypsum is formed from anhydrite through the entrance of water. Near Ellrich the change has formed mounds of gypsum in concentric shells one and one-third meters (52 feet) high, often hollow in the interior. The force of the expansion has been sufficient to break crystals of quartz and dolomite in the layers above.[2]

§ 7. Gypsum Deposited from Sea Water.

The most generally accepted theory of origin of large deposits of gypsum and salt has been that they are evaporated from salt water lakes or arms of bays and seas cut off from the main ocean. This theory has been given for the Iowa, New York, Virginia, and Kansas fields in the reports on salt and gypsum in those states. In the Kansas report, the writer endeavored to picture the history of the changes resulting in the evaporation of gypsum and salt laden water in a bay whose water retreated to the southwest in Permian time.

Examples of these changes can be found in the salt lakes and ocean gulfs and bordering seas at the present day. In southern Europe are excellent examples of the results of the evaporation of salt lakes, and in this country the best examples are seen in the Great Salt Lake and in the neighboring salt lakes of Utah and Nevada. Lake Bonneville in the Quaternary period of geological time covered an area of 19,570 square miles with a depth of 1,050 feet, and its waters were fresh. Through evaporation, its level was lowered below the place of outlet at the north, and its waters in the course of time became more and more saline. This evaporation has continued until the present remnant, Salt Lake, has less than 2,400 square miles of area with an extreme depth of 50 feet, with its waters almost a concentrated brine with specific gravity of 1.1. The total amount of salts in this lake water is 15%, of which 11.8% is common salt (NaCl).

The waters of the Dead Sea afford another example of concentrated brine due to evaporation. In this water there is 26% of salts, but differing in composition from the American lake. There is only 3.6% of the com-

[2] Possibly much of the Michigan gypsum has been anhydrite. The specific gravity of gypsum being from 2.314 to 2.328 according to Dana and that of anhydrite from 2.899 to 2.985, the substance of gypsum in the shape of anhydrite and water (20.9% H_2O plus 79.1% $CaSO_4$) would have a specific gravity of between $\left(\frac{20.9 \times 1 + 79.1 \times 2.8999 \text{ to } 2.985}{100}\right) = 2.401 \text{ to } 2.569.$

Therefore the substance of gypsum in the form of anhydrite and water is more condensed than in the shape of gypsum; therefore pressure would tend to aid its formation or change into the former shape. This may be the reason of the occurrence of anhydrite in the deep well samples, as well as its formation in boilers and similar places under pressure. L.

mon salt and 15% of the magnesium chloride as compared with 1.5% of this salt in the Great Salt Lake. The amount of gypsum in the waters of the two basins is nearly the same, 0.086%. The composition is given in the following table:—[1]

	Great Salt Lake.	Dead Sea.
Chloride of sodium	11.8628	3.6372
Chloride of magnesium	1.4908	15.9774
Chloride of calcium	....	4.7197
Chloride of potassium	0.0862	0.8379
Bromide of magnesium	....	0.8157
Sulphate of calcium	0.0858	0.0889
Sulphate of potassium	0.5363	....
Sulphate of sodium	0.9321	....
Water	85.0060	73.9232
	100.0000	100.0000

Ocean water according to the analyses of the Challenger Reports contains 3.5% of mineral salts of which three-fourths is common salt, sodium chloride. The waters of the Atlantic show the following varieties and proportions of salts:—

	Per cent.
Chloride of sodium (common salt)	77.758
Chloride of magnesium	10.878
Sulphate of magnesium	4.737
Sulphate of lime (gypsum)	3.600
Sulphate of potassium	2.465
Carbonate of lime	0.345
Bromide of magnesium	0.217
	100.000

When such a body of water is cut off and evaporated, the gypsum is deposited after 37% of the water is removed, and common salt only after the removal of 93%. The normal order would be a deposit of gypsum and then a much heavier deposit of salt. But as 93% of the water must be evaporated before the salt would be thrown down, the evaporation might go far enough for the deposition of gypsum, but not far enough for the salt, or the salt might be deposited and subsequently removed by solution. The first condition apparently took place in the Kansas gypsum area, and both in Michigan. Gypsum deposits are more widespread in nature than salt, but they usually occur in thinner beds.

In most areas the amount of gypsum found is far greater than the amount found in ocean water that would cover the area at reasonable

[1] Geikie Text Book of Geology, p. 383; 1885.

depths. The present condition in the Mediterranean sea seems to aid in the explanation of the formation of such deposits and has been cited for this purpose in the discussion of the Kansas[1], Iowa[2], and former accounts of the Michigan areas.[3]

§ 8. Mediterranean Sea.

The most complete study of the composition and the currents of the Mediterranean sea have been made by Capt. Nares and Dr. Carpenter of H. M. S. Shearwater in 1871.[1] They found the basin of this sea to be 6,000 feet deep, separated from the ocean at the straits of Gibraltar by a ridge 1,200 feet high. The water of the Atlantic outside the ridge had a specific gravity of 1.026. In the western part of the sea the gravity is 1.027, and at the eastern part of the sea it is 1.03. The proportion of salts in the ocean was 3.6%, and in the Mediterranean is 3.9%. Passing over the dividing ridge were two currents, one over the other. The upper was inflowing and the lower outflowing. The water of the basin is not concentrated enough to deposit salt and gypsum, but it is gaining in quantity of salt held in solution.

So it is thought that the water in the old seas or gulfs of Kansas and Iowa received additions of salt and gypsum by inflowing water and thus increased the thickness of the deposits. This theory is thought to explain the great thickness of the salt deposits at Stassfurt (1,000 feet), and at Sperenberg (3,000 feet) in Germany, which could hardly have been deposited except from a continuous supply of salt water.

§ 9. The Michigan Carboniferous Salt Sea.

The area of rocks in Michigan formed after the deposition of the Marshall and Kinderhook series is approximately circular in outline with a radius of 85 miles, giving an area of 22,686 square miles. As will be later shown, the sea covering this area in Osage time was 700 feet in depth, and assuming the average depth to be 326 feet, based on well records, there would have been about 1,280,000 billion gallons of water.

The analyses of the Atlantic ocean water show 93.3 grains of gypsum to the gallon. If this Michigan sea had that proportion it would have yielded nearly nine billion tons of gypsum.

The thickness of gypsum at Grand Rapids is 18 feet and at Alabaster is 20 feet. The approximate area at Grand Rapids is 24 square miles and at Alabaster, 10 square miles, and while the gypsum does not by any means keep this thickness given over these areas and is even absent in parts of the area, it has probably been removed by solution since its deposition. These conditions would give 1,237,764,000 tons of gypsum.

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[1] University Geol. Survey of Kan., Vol. V. p. 138.
[2] Iowa Geol. Survey, Vol. 12, p. 123.
[3] Geol. Survey of Michigan, Vol. V, Part 2, p. 15.
[1] Published in Proc. Roy. Soc. Vol. XX, p. 97. 414; 1872, cited in Enc. Brittanica. Vol. XV, p. 821.

If the assumption is made, that the gypsum covered all the area with a thickness of 20 feet[1], then it would require 917 billion tons or 90 times the amount of water in this original sea, and one would need to look for the ridge or barrier over which the ocean waters flowed to supply the water for the gypsum, unless the same was supplied as in the Great Salt Lake by land drainage.

§ 10. Caspian Sea.

For a modern illustration of the conditions in this Michigan sea, the Caspian[2] sea might be cited. Into the northern part of this sea empty the Volga, Ural, and Terek, rivers bringing in a large quantity of the fresh water, so that the sea water is nearly pure, with a specific gravity of 1.009. This small amount of salt, according to Von Baer, is partially due to the fresh water brought in and also to the number of shallow lagoons surrounding the basin, each being a sort of natural salt pan. At Novo Petrovsk a former bay of the main sea is now divided into a number of basins showing all degrees of saline concentration. One of these has deposited on its banks only a thin layer of salt, a second has the bottom covered with a thick crust of crystals, a third is a compact mass of salt, and a fourth has lost all the water and is a mass of salt covered with sand. On the other side of the sea in the peninsula of Apsheron are ten salt lakes from one of which 10,000 tons of salt are annually produced.

The concentration is seen on the greatest scale in the Karaboghay (Black Gulf) of the Caspian, whose nearly circular shallow basin is about 90 miles across, and almost entirely cut off by a long narrow spit of land communicating with it by a channel not over 150 yards broad and five feet deep. Through this passes a current with an average velocity of three miles an hour, accelerated by the western winds.

This current is due to the indraught produced by excessive evaporation due to the heat and winds from the surface of the basin, which at the same time receives but little return from streams. The small depth of the bar prevents a counter current of highly saline water into the sea. The current carries into the Black Gulf, according to Von Baer, 350,000 tons of salt daily. If the bar should be elevated and cut off the basin from the sea, the gulf would quickly diminish and become a salt marsh, later drying up and leaving a heavy salt deposit. North of this gulf over the Russian steppes are sands and marls intermingled with salt, representing former salt lakes now dried up.

§ 11. The Michigan Caspian Sea.

The Kinderhook sea of the American continent was an interior sea with a bay extending north-east into Michigan. In this bay were

[1] That a large part was covered is indicated by the occurrence of $CaSO_4$ also in the Alma, Midland Mt. Pleasant, and Bay City wells.
[2] Von Baer, Bull. Acad. St. Petersbourg, 1855-6, quoted in Enc. Brittanica, Vol. V, p. 176.

laid down the Marshall sandstones. The close of the period was marked by an uplift in this area and a retreat of the sea southwestward, finally exposing a wide area of land in southern Michigan and northern Indiana. At Lafayette, Ind., the floor of this sea rose at least 563 feet above sea level.[1] North of this land barrier was a large interior sea with a floor near Grand Rapids 375 feet above sea level, lower by nearly 200 feet than the ocean to the southwest, but surrounded by the Marshall series, at this time dry land 777 (Kalamazoo), 983 (Coldwater), to 1,000 feet (Hillsdale) above sea level on the south; 700 feet (Huron County) on the east; and 755 feet (Grayling) at the north;—a sea like the Caspian, with a depth at first of probably 700 feet or more, and an area of 22,686 square miles.

In this sea were elevations and depressions, the ridge at Lansing 500 feet above sea level, and a depression east of Saginaw 380 feet below sea level separated by a ridge 187 feet above the sea floor.

This sea probably had its tributary streams coming from the highland at the north and northeast flowing down across the recently emerged flats of the Waverly and Marshall land, bringing in a supply of sediment and doubtless salt and gypsum from the Salina beds at the north.

The lake basins of Michigan and Huron were not in existence at this time but belong to a much later chapter in the geological history of our continent. The irregular clay seams and the clay bedding planes in the gypsum represent an influx of sediment, wind blown material, or the result of tidal currents, or material brought in by streams.

As the evaporation of these waters went on, the first deposit would be carbonate of lime thrown down when the specific gravity was raised to between 1.0506 and 1.1304. By further concentration, when the specific gravity was between 1.1304 and 1.22, gypsum would be deposited. At this time 37% of the water must have been evaporated. If the sea was originally 700 feet in depth, it would now be 440 feet deep, still covering the Saginaw ridge but exposing the Lansing ridge. Thus would be formed smaller basins in which evaporation would go on rapidly. Further well records might give a clue to the other basins separated by ridges. The sea would gradually become like the modern Caspian with smaller basins around the main sea, in which all degrees of concentration would be found.

In the deep basins near Saginaw, the dividing ridge would be exposed before the concentration produced the deposition of salt. In the evaporating basin the deposit of gypsum would occur especially around the borders of the basin, and by the influx at first of water across the Saginaw ridge the contracting basin of water was probably renewed, resulting in the 20 or 25 feet of gypsum in the area south.

[1] The references are to present-sea level. It is assumed that there has been no post carboniferous folding.

The normal order should be a dolomite limestone floor on which would be a deposit of gypsum covered by layers of salt. In the present developed area the gypsum rests on the limestone or dolomite floor but with no salt beds over it. The rock salt deposits are below the gypsum series in the Monroe or Salina series. Further, in the Marshall and Grand Rapids series at Saginaw, Grand Rapids, etc., the salt wells secure their salt wholly from natural brines. Rock salt occurs only occasionally in veins in the gypsum.

If the Michigan interior sea evaporated completely then there would have been, on the assumption that the waters were like the present Atlantic ocean, 17.9 times as much salt as gypsum. This would have been deposited over the gypsum and especially in the lower part of the basins towards the interior where the waters deprived of their gypsum had retreated on evaporation, but in the same geological series. The salt might later have been removed by solution through downward circulating waters dissolving out the more soluble salt. The gypsum now remaining shows marked effects of solution and these effects would have been much greater in the salt. The salt laden waters would flow downward along the slope of the rock and percolating through would work up under the hydrostatic pressure, as it approaches the center of the basin, into the overlying Parma sandstone, which is more gypsiferous than the underlying Marshall.[1]

Another possible explanation of the final history of this sea is found in the great extension of the sea in the next epoch resulting in the formation of the St. Louis limestone. The sea at this time extended its borders north and south and passed across the Michigan interior basin to Grand Rapids on the west, and on the east into Huron county. Possibly this took place before the Michigan sea had disappeared by concentration. From the sandstones and shales of the Michigan series found in the well borings of the interior it would seem that the ocean flowed over the southern barrier into the interior sea a number of times before the greater or culminating St. Louis inundation, and thereby deposited these sediments in which no gypsum or salt are found, as the water was diluted and the specific gravity was not high enough to cause precipitation. These overflows, local in their occurrence, cannot be correlated with other sections unless with those of the Logan series of Ohio whose origin may be similar.

In the deeper Michigan borings gypsum seems to be replaced by anhydrite, but it is stated that where the depth of water is 325 feet, thus giving a pressure of ten atmospheres, anhydrite is formed instead of gypsum.[2]

The theory as outlined for Michigan is based on the study of comparatively few well borings, and on a comparative study of the present conditions in the Caspian sea and those of the Michigan area as far as they

[1] See analyses in U. S. G. S. Water Supply Paper No. 31.
[2] New York State Museum Report, Vol. III. No. 11, p. 11, 1893. See previous foot note, page 185.

can be determined. There is a wide range of probability involved and while the theory is advanced as a theory resting on limited data, it seems probable that it represents approximately the conditions of the origin of these deposits.

§ 12. Vein Deposition.

Gypsum is of course readily precipitated from waters which hold it in solution. It gave much trouble by coating the casing of salt wells. It is not infrequently found in little isolated crystals in shales. I have also seen it coating the cleat or vertical joints of coal. It has been found in the copper country. Large clear selenite was found at the National mine.

All these occurrences are, however, of course only mineralogical curiosities. L.

CHAPTER XII.

GYPSUM AS A FERTILIZER.

§ 1. Early Experiments.

Ground uncalcined gypsum stone or land plaster, as a soil fertilizer, has at times been endowed, by writers on this subject, with the most wonderful and mysterious life-giving power. Other examples have been cited to show that it had no effect whatever, but such examples are rarely given in the earlier writings. From some of the accounts given it would seem as though land plaster used with certain crops would give a three years' yield in one. The good effects of land plaster have been assigned to its influence on the air, on water, and on the soil itself.

Among the earliest accounts of gypsum as land plaster are those of Virgil who writes of the value of impure gypsum on cultivated fields, and the early farmers of Britain and of Lombardy had great faith in its use.

In this country, down to the year 1889 nearly two-thirds of the quarried gypsum was ground into land plaster. In the early 70's in Michigan, the mills could not supply the demand, though they were run night and day, and the material sold at a high price of $4.50 a ton. In 1890 the uses of gypsum in this country were reversed in ratio, and nearly twice as much rock was calcined as was used for fertilizer. By 1893 the proportion was three to one, and in 1898 the amount of gypsum calcined was six times that ground into land plaster.

There were several causes for this change. One was the growing doubt with regard to the wonderful properties of land plaster. Fields which had given greater yields by its application year after year, now failed to respond to the treatment. As it was sometimes expressed, the soil had grown tired of this form of food. Prof. F. S. Kedzie says that:—"Land plaster consists of elements which are rarely found deficient in soils.[1] Hence it seems reasonable to suppose that the beneficial action of $CaSO_4$ is certainly not direct but through secondary action. Its benefits are practically confined to the leguminous family, and the lessened use is due to a greater knowledge of what the crops remove from the soil, as well as to the discovery of phosphatic deposits and increased use of phosphatic

[1] CaO is always present, and SO_3 very commonly in lower Michigan waters. See U. S. G. G. Water Supply, paper No. 31, and annual report for 1902.

GYPSUM EARTH DEPOSIT AND MILL OF ACME CEMENT PLASTER COMPANY.

From Univ. Geol. Survey of Kansas, Vol. V, Plate XXI.

manures. Since the fertilizer law passed in 1885, the exact percentage of different constituents in commonly used fertilizers is known.

Then, also, commercial fertilizers composed of various ingredients became popular. Large companies were organized over the country, who by the use of large capital, careful preparation of materials aided often by judicious advertising were able to sell at a reasonable price patent phosphate fertilizers embodying the good points of gypsum and giving other valuable qualities in addition.

New uses for calcined plasters were devised especially in its use for hard wall plaster, Alabastine, Anti-Kalsomine, etc., which enlarged the demand and opened a line of manufacture which proved more profitable than the grinding of the crude material.

The opinions of agricultural chemists do not always agree and often opposite views are expressed in standard books of reference. The reports of agricultural societies down to about 1870 nearly always contained reports from farmers describing their experiments with gypsum on various crops. No agricultural treatise was complete without a discourse on this subject. At the present time it is rare to find gypsum discussed in such society meetings and modern books of agriculture devote but a paragraph to the subject of land plaster. The following is a list of references to the subject in the reports of the Michigan State Board of Agriculture:

Gypsum Deposits in Michigan.

Year.	Page.
1853	337
1856	585
1871	199
1886	150

Plaster.	Year.	Page.
Action of, on land	1875	257
	1879	91
Amount per acre to use	1875	264
	1886	72
Apple trees dusted with	1879	280
Article on agricultural value of, by Dr. R. C. Kedzie	1875	256
Clover and	1877	149
Compared with other fertilizers	1875	265
Corn and	1878	162
experiments	1877	78
Curculio, fought by	1888	224
Discussed	1850	294
	1864	85
	1879	81, 91
	1883	100
	1886	74
Drainage carrying out, of soils	1875	262
Dust for insects	1879	280
	1888	224
Experiments with	1865	236
	1866	56
	1877	78
	1878	215

The history of gypsum as a fertilizer[1] dates back a little over a hundred years. A century has seen its rise in the estimation of agriculturists and its decline. The land plaster industry started probably in Wurtemberg but was first brought to the attention of the world by the Economic Society of Berne, Switzerland. The first account that can be found of this use of gypsum is in the Memoires de la Societé économique de Berne in 1768. This society had submitted the following theme for public discussion, "Description of the different kinds of earth and methods for mixing them to render the soil fertile."

Among the papers submitted to the society was one by a clergyman, J. F. Mayer of Kupferzell in Würtemberg, which was given first rank by the jury of the society of Berne. In the main paper there is no reference to gypsum, but in an appendix was a brief note on gypsum as a fertilizer, which according to Prof. Chuard brought about almost a revolution in agricultural methods of fertilizing soils. The society requested Mr. Mayer to give them further knowledge on this subject, which he did in the following words:—

(Translated from the French.)

"It is only two years since one has entertained the thought that a stone of which little account was taken, was nevertheless well suited to attract to itself the oil and salt of the air, and consequently suitable to be placed on the meadows and to enrich them. When it is found crude, it is re-

[1] For the account of this early history, the writer is indebted to Prof. Chuard of Laussanne Switzerland, who has kindly placed at hand a number of his papers on this subject.

duced to powder, and after it is crushed it is spread on the meadows or upon sterile soils of whatever nature they may be. Over one acre one scatters eight fri (a measure 13 inches in diameter and 8 inches high) and this fertilizer furnishes the best forage and the best clover one can imagine. It has greater effect if calcined, but the best effect is obtained by adding to it two fri of wood ashes and eight handsful of salt, and the whole soaked in a half pail of manure water. Let these materials be well mixed, then let them lie eight days, after which having stirred them, one may spread them on the soils to be fertilized. Our people profit by it continually and the experience for two years has justified the first trials. As soon as one is quite convinced, and one cannot conceive it otherwise, that all plants are composed of salt, oil, and earth, one will be as easily persuaded that gypsum flour scattered over wheat, oats, barley, and vegetables, ought to produce the same effect. The experiment has already been tried."

The society of Berne realizing the importance of this communication, decided to have the experiments at Kupferzell repeated at a number of places, and these results were published in the Memoir for 1771, especially in two communications, one by N. H. Kirchbergner, and the other by M. Tschiffeli.

The paper by Kirchbergner is an account of a series of experiments on clover, lucerne, and radishes, and the author expresses his admiration over the marvelous results obtained from the use of this gypsum fertilizer. On an acre (arpent) twelve measures of gypsum, costing three francs and twelve pence produced more forage than 12 cars of manure costing not less than 72 francs. He preferred calcined gypsum to raw, not for the effect but because it was more readily pulverized. The gypsum produced a greater effect the first year but also gave an increase in crops the second year. It had more effect on dry earth than on wet, was better on heavy soil than light. Sowed in the spring on natural forage it produced its best effects on the second cutting.

The memoir of Tschiffeli proved at the start that gypsum was excellent material for the soil and not injurious. The conclusions of the experiments were the same as in the first memoir. On wheat becoming weak in its growth at the first of June, gypsum applied in double portion at a dry time, brought about at the first rain an almost miraculous growth and made a good harvest. Both of these men observed that no culture profited with gypsum like trefle, luzerne and the plants of this same family.

These experiments were repeated by others and the use of gypsum fertilizer spread over France, then over Germany and England, and became especially prominent in the United States where the gypsum was imported from the Monte Martre quarries near Paris.

§ 2. Early Use in America.

The early farmers in Maryland, according to Rees, used gypsum fertilizer with great success, and this writer states that:

"It was most beneficial on high and sandy soils and had good effect on wheat, rye, barley, peas, potatoes, cabbage, clover and all natural grass crops. The invariable result of the several experiments incontestibly proves that there is a most powerful and subtle principle in this tasteless stone, but by what peculiar agency or combination it is capable of forcing vegetation in such an instantaneous and astounding manner is a mystery which time reserves for others to unfold."

Benjamin Franklin called attention to the value of gypsum as a fertilizer for grass, by sowing the land plaster in a clover field near one of the main roads in Pennsylvania so as to form the sentence, "This has been plastered with gypsum," and the letters it is said could be detected readily by the height and color of the clover where the gypsum had been sown.

Grece's American Observations.

Mr. Chas. F. Grece[1] writing of his observations in the United States and Canada in 1819 in the Quarterly Review, says:

"This valuable manure, almost unknown though very easy to obtain, merits the attention of every farmer. There is scarcely a farm in the provinces but it might be applied to with advantage. The practice of nine years on the following soils and crops may suffice to prove its quality. On a piece of poor yellow loam I tried three grain crops without success, with the last which followed a hoe crop I laid it down with barley and the return was little more than the seed. The grass seed took very well. In the month of May of the following year I strewed powder of plaster at the rate of one minot and one peck to the arpent (acre). In July the piece of land being mowed the quantity of the grass was so great that it was not possible to find room to dry it on the land where it grew. The product was five large loads of hay to the arpent. It continued good for five years. . . . I tried plaster on cabbages and turnips, but did not perceive any good effects. From the frequent trials of this manure on various soils it is evident that it is applicable to both light and strong soils for top dressing of succulent plants."

Ruffin's Experiments.

Ruffin, in his book on Calcareous Manures,[2] written in 1832, states that,

"There is no operation of nature heretofore less understood or of which the cause or agent seems to be so totally disproportionate to the effect as the enormous increase of vegetable growth from a very small quantity

[1] Vol. XXIII, pp. 147-150; 1820.
[2] Page 151.

of gypsum in circumstances favorable to its action. All other manures, whatever may be the nature of their action, require to be applied in quantities very far exceeding any bulk of crop expected from their use. But one bushel of gypsum spread over an acre of land fit for its action may add more than 20 times its own weight to a single crop of clover hay."

Mr. Harbe[1] in the German Land-Owners meeting in 1841, stated that he had found gypsum of most value on clover and peas. If applied to peas, and oats were planted the next year, there was a greater yield, but the plaster applied directly to an oat field produced no effect. The discussion at this meeting brought forth contradictory remarks with regard to the use of gypsum on meadows. In the Gardener's Chronicle for 1841 (p. 785), gypsum was stated to be of little use on corn, but useful for clover, grass, potatoes, and turnips, and was especially good on light or chalky land and should be sown broadcast in proportion of about five bushels to the acre.

Harris' Experiments.

Mr. Harris,[2] in 1878, gave an account of his experiment on oats at the Moreton farm near Rochester, N. Y., in the following table:—

	Bushels to acre.	Weight per bushel.	Pounds of straw.
On field No. 1, without manure	36	22	1958
On field No. 2, with 600 lbs. of gypsum	47	26	2475

There was an increase of 11 bushels to the acre, and nearly one-half ton more straw.

	Bushels to the acre.
On potatoes with no manure	95
" " " 100 pounds of plaster to the acre	101
" " " 150 pounds of ammonia sulphate	140

He did not find gypsum valuable as a direct fertilizer for wheat, but quotes an old adage that, "clover is good for wheat, plaster is good for clover."

§ 3. Theory of De Candolle and Chaptal.

The early theory to explain the action of gypsum on soils, very attractive and popular in its day, was that of De Candolle,[3] who looked upon gypsum as a stimulant to the leaves of plants. This theory, which became prevalent, stated that "sulphate of lime acts as an irritant in favoring respiration and exhalation of plants."

Chaptal modified this theory somewhat, and regarded the stimulation

[1] Agricultural Society of England, Vol. 333, p. 224; 1842.
[2] Talks on Manures, pp. 126, 254: 1878.
[3] Annales de Chimie, 55, p. 312.

as due to the saline character given to the sap by the presence of gypsum, and as this mineral dissolved very slowly, it would gently stimulate and not irritate.

§ 4. Gypsum as Direct Plant Food.

The examination of the ash of plants was made long ago, and formed the basis for a number of theories concerning the action of plaster on plants, especially for those theories which regarded gypsum as a direct element of plant food.

Analyses of Plants.

	Water.	Nitrogen.	Ash.	Potash.	Soda.	*Lime.*	Magnesia.	Phosphoric acid.	*Sulphuric acid.*	Silica.	Chlorine.
Pasture grass	782	7.2	21.2	8.1	0.3	2.6	1.2	1.9	0.7	4.1	2.1
Red clover, young	860	6.0	14.0	5.1	0.3	3.9	1.3	1.7	0.3	0.4	0.6
" " in bud	820	5.2	14.7	5.5	0.3	4.5	1.6	1.5	0.4	0.4	0.5
" " in flower	800	4.8	13.7	4.4	0.3	4.8	1.5	1.3	0.4	0.4	0.5
Alfalfa, (early flower)	740	7.2	19.2	4.5	0.3	8.5	0.9	1.6	1.1	1.8	0.6
White clover, in flower	805	5.6	14.3	3.1	1.0	4.3	1.4	1.8	1.1	0.6	0.7
Potato plant	750	3.4	9.5	5.8	0.3	0.3	0.5	1.6	0.6	0 2	0.3
Oats (grain)	143	17.6	26.7	4.8	0.4	1.0	1.9	6.8	0.5	10.5	0.3
Maize (grain)	144	16 0	12.4	3.7	0.1	0.3	1.9	5.7	0.1	0.3	0.2
Spring wheat (grain)	143	20.5	18.3	5.6	0.3	0.5	2.2	9.0	0.2	0.3	0.1
Winter wheat (grain)	144	20.8	16.8	5.2	0.3	0.5	2.0	7.9	0.1	0.3	0.1
Garden beans (seed)	150	39.0	27.4	12.1	0.4	1.5	2.1	9.7	1.1	0.2	0.3

The translation of the German work by Prof. Sprengel, published in the Agricultural Gazette in 1844 (p. 858), states that gypsum suffers no decomposition in the soil but passes in its entire state into the substance of the plant.

According to Johnston,[1] in 1849, the benefit of gypsum to clover is due to its decomposition in the soil, thereby furnishing lime and sulphur to the plants. This author believed the gypsum did not fix ammonia, and further absorbed very little moisture from the air. According to his experiments,

1000 parts of soot gained from moist air 36 parts by weight.
" " " coal ashes gained 14 parts by weight.
" " " burnt clay " 29 " " "
" " " chalk " 4 " " "
" " " gypsum " 9 " " "

§ 5. Retention of Ammonia by Gypsum.

Moist gypsum in contact with ammonium carbonate has been supposed to form ammonium sulphate according to the formula,[2]

$$(NH_4)_2\ CO_3+CaSO_4=(NH_4)_2\ SO_4+CaCO_3$$

If used in stables and other places it serves to retain to some extent the

[1]Manures, pp. 454-481; 1844.
Use of lime in Agriculture, p. 204; 1849.
[2]U. S Dept. of Agric. No. 64, Division of Soils, 1899, Cameron, p. 155.

ammonia which otherwise might escape into the air. This use of land plaster is recommended by Snyder[1] and also by Wiley.[2]

It was early discovered that the atmosphere contained carbonate of ammonia which was carried down to the earth in rain water, and there it was thought to be held or fixed by gypsum. A good statement of this theory is given in Browne's American Muck Book,[3] written in 1851. The carbonate of ammonia acted on the sulphate of lime so as to form sulphate of ammonia and carbonate of lime. This prevented the escape of the volatile carbonate of ammonia back into the air. A computation was made which showed that 100 pounds of common unburned gypsum would fix 20 pounds of ammonia containing 16½ pounds of nitrogen. This would furnish a very large amount of valuable food to plants for their use; but now it is known that the amount of ammonia in the air is so small that it is very doubtful whether the amount so fixed by gypsum is even appreciable to the plants.

This theory was held and much elaborated by the chemist Liebig, who calculated that if 40 pounds of gypsum were placed on a field, and only one-tenth of it entered plants as ammonia sulphate, theoretically there would be nitrogen enough for 100 pounds of hay, 50 pounds of wheat, or 60 pounds of clover.

Stockhardt's Theory.

Some have held that the gypsum fixed the ammonia formed within the soil by decaying vegetable matter; and further, that the gypsum hastened this decay. Davy tried a number of experiments to disprove this latter statement and he found that meat mixed with gypsum and allowed to stand a considerable period of time showed not the slightest difference in time of putrefaction, from meat not so treated. The former part of the theory is given in a brief summary by S. Stockhardt:[4]

"Gypsum acts chiefly through its sulphuric acid, which on the one side procures soluble ammonia from the humous constituent of the soil and furnishes this to the plant at the period when it is especially inclined to the production of leaves and stems; and on the other side, strengthens and increases the power of plants to absorb ammonia from the atmosphere, and this in greater proportion as they are more abundantly endowed with delicate and juicy leaves and are thus already fitted by nature to make a more abundant use of the atmosphere."

§ 6. Van Wormer's Experiments.

Experiments by Lewis H. Van Wormer on the fixation of ammonia by land plaster conducted under the direction of F. S. Kedzie for a senior agricultural thesis in the Michigan Agricultural College in 1895, seem however, to show that dry plaster has but little power to absorb and

[1]The Chemistry of Soils and Fertilizers, p. 161, 1899.
[2]Principles and Practice of Agricultural Analysis, Vol. 2, pp. 307-308; 1895
[3]Pages 68 to 75.
[4]A Familiar Exposition of the Chemistry of Agriculture, p. 226; 1855.

affix ammonia. Dampened plaster absorbed ammonia but lost most of it on drying out. This led Mr. Van Wormer to conclude that the power of absorption depended more upon the water than upon the plaster. It seems, however, to be possible that the water acted as a necessary medium for reaction and that then the reaction above stated may have gone on. Mr. Van Wormer experimented under conditions both abnormal and normal. In one set of experiments he placed under bell jars a watch glass of ammonia and a watch glass of plaster or some other substance under each. Five grams of dry plaster under the jars with five c.c. of ammonia left for more than ten days contained only from 0.1 to 0.2 c.c. of ammonia less than would be absorbed by 3. c.c. of water. In only 48 hours it contained 2.5 respectively 3.3 of ammonia.

Another line of experiments was to place water, plaster and sulphuric acid in crystallizing dishes under the floor of a stable reeking with ammonia. After four days 15 grams of plaster moistened with 15 c.c. of water, 15 c.c. of water straight and 15 c.c. of sulphuric acid had absorbed relatively 25.8, 10.8, and 199.4 c.c. of standard decinormal solution of ammonia containing 1-7 grams of ammonia per liter of water.

A similar experiment with 5 grams of plaster and 5 grams of sand each added to 5 c.c. of water, gave for the plaster 7.4 and 4.3 c.c. of the ammonia solution in four days, and in another case 3.5 to 1.3 c.c.

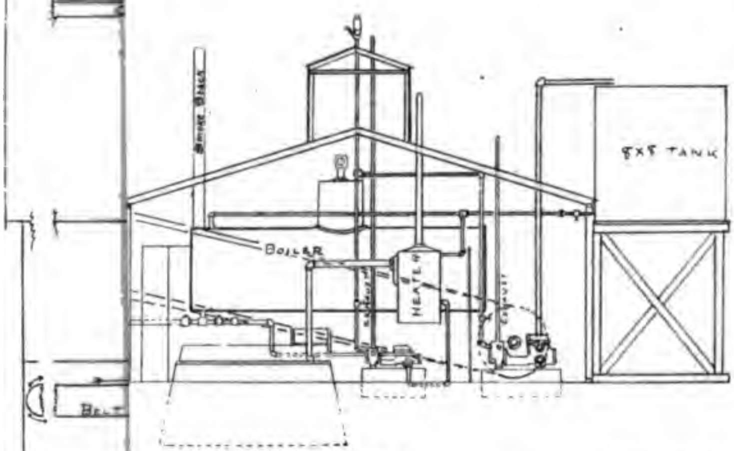
In testing plaster in comparison with muck (peat) in a similar way 5 grams of each with excess of water absorbed in three days 10.2 c.c., and 32.1 c.c. respectively and in 24 hours 7.5 and 34.3 c.c., and in three days under the stable floor 6.6 to 31.5 c.c. In an experiment under bell jars with barely enough water to wet the two that ratio was 1.7 c.c. to 37 c.c., again in favor of the muck. Further experiments show that muck or peat was a much more effective fixing agent than plaster.

§ 7. Boussingault's Experiments.

Boussingault.[1] in 1841 spread gypsum over a clover field, and then analyzed the clover from the land where gypsum was spread and where it had not been spread. He found a great increase in amount of ash, which represented an increase in all the mineral constituents, but especially in lime, magnesia, and potash. These experiments, carried on for two years on the same land, are given in the following table:—

	Land with gypsum.	No gypsum.	Land with gypsum.	No gypsum.
Ashes free from CO_2	270.0	113.0	280.0	97.0
Silica	28.1	22.7	10.4	12.7
Oxides (iron, manganese, alumina)	2.7	1.4	?	0.6
Lime	79.4	32.2	102.8	32.2
Magnesia	18.1	8.6	28.5	7.1
Potash	95.6	26.7	97.2	28.6
Soda	2.4	1.4	0.8	2.8
Sulphuric acid	9.2	4.4	9.0	3.0
Phosphoric acid	24.2	11.0	22.9	7.0
Chlorine	10.3	4.6	8.4	3.0

[1] Rural Economy, 1887.



POWER HOUSE, SIDE ELEVATION
Figure 3

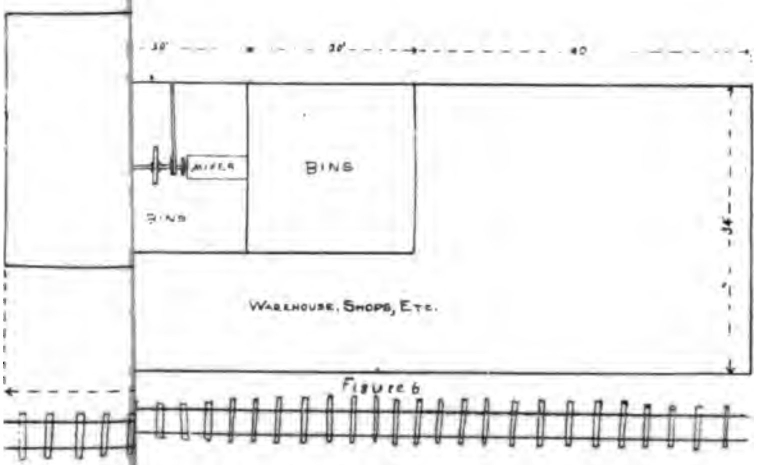


Figure 6

ground plan.
ground plan.
ound plan.

This table gives the number of kilograms of the elements in clover from a hectare of ground, and it certainly shows that gypsum has had considerable effect on the clover. The great increase of potash shown by these analyses was explained as due to the direct action of the gypsum on the soil or was left out of account altogether. It is explained in another way by more modern theories as will be described in another section.

§ 8. Davy's Theory.

Sir Humphrey, and others before and after his time, have regarded gypsum as a direct source of plant food. Davy found that clover contained about two hundred weight per acre of sulphate of lime, and that this was the amount of gypsum which produced the greatest benefit on the soil, so he argued the gypsum entered the plant as sulphate of lime.

An examination of the table of plant composition given above shows that lime and sulphuric acid are present in the plants benefited by the gypsum. Other tables give sulphur as an element in plant ash rather than sulphuric acid. So sulphur was supposed to come from the gypsum which did not enter directly as plant food, but was first broken up into its parts. This action was supposed to depend on the presence of humous acids, whereby the gypsum was broken up into humate of lime and sulphuric acid. If too little humus was present this action would not take place, and on such soils gypsum would be of no value; if too much humus, the action would be rapid, setting free so much sulphuric acid that it would corrode the roots of the plants and so prove injurious. The lime shown in the table of plant analyses was supposed by many to result from the decomposition of the gypsum.

The sulphur of plants probably comes from other sulphates more easily decomposed than gypsum, though a small portion may result from this mineral. Most of the lime is certainly derived from other compounds, especially the carbonate of lime, which is readily soluble.

§ 9. Recent Theory of Storer.

Gypsum is now[1] thought to act as a fertilizer of soils in three ways, one mechanical and two chemical.

First, lime is known to flocculate loose soils; that is, collects together the loose particles and so makes the soil more granular. This may be illustrated by placing lime in a muddy liquid, and the mud will flocculate and settle to the bottom. Lime has also an opposite effect on tough clay soils, where it granulates them, breaking the soil up into finer particles. Gypsum as a lime salt, appears to act to a small extent in these ways and

[1]Chemistry of Agriculture, Vol. 1, pp. 206-216; 1887.

so improve the mechanical condition of the soils; but in this respect other lime compounds act more powerfully and more rapidly, and so would be better.

Second, Storer has pointed out that gypsum has nearly one-half its weight in oxygen and gives this up to many substances, and so may act upon nitrogenous and carbonaceous substances in the soil.

Third, and most important, it has been shown that gypsum decomposes the double silicates in the earth, setting free potash as a double sulphate. According to Storer the action is as follows:

$$\left.\begin{matrix} Al_2O_3 \\ CaO \\ K_2O \\ H_2O \end{matrix}\right\} x\,SiO_2 + CaOSO_3 = \left\{\begin{matrix} Al_2O_3 \\ CaO \\ CaO \\ H_2O \end{matrix}\right\} x\,SiO_2 + K_2\,OSO_3$$

By this means the potash in solution reaches the roots of the plants. This method of supply is of special advantage to the deep rooted plants, as in the order Leguminosae—the clovers, beans, etc., which contain a considerable percentage of potash in their tissues.

Soils with abundant potash would not need gypsum, and soils with no potash compounds would not be benefited in this respect by gypsum.

The gypsum is then to be looked upon as an excitant rather than as a form of plant food. Land plaster according to this theory uses the potash of the soils more readily than it is used naturally and so after a few years the soil fails to respond to the gypsum dressing, and the soil is said to have grown tired of this treatment. The experience of many farmers is that gypsum is very beneficial for a few years and after that it fails to produce any effect. This is expressed in the old English adage, "Lime enriches the father, but impoverishes the son."

§ 10. Experiments in Kansas.

Recent experiments made in Kansas[1] on prairie and tame grasses appear to show that on the soils in the Manhattan region, plaster has but little effect.

On prairie grass the average yield on non-plastered plats was 1.248 tons to the acre. On plastered plats the yield was 1.256 tons.

The experiments on tame grass are shown in the table:

	1st cutting. Pounds.	2d cutting. Pounds.	Total yield per acre. Tons.
Plaster, 800 pounds per acre.............	1,076¾	676¾	3.506
Plaster, 400 pounds to the acre...........	1.012¼	690	3.404
Nothing.................................	1.008	690	3.396

[1] Bull. 32 Kansas State Agricultural College Experiment Station. pp. 239, 240; 1891. Bull. 30, p. 201, 202: 1891.

The experiment gave an increase on the plastered land of 165 pounds of hay on one and one-fourth acres, and the fertilizer cost of this land was $1.80.

On corn the yield on non-plastered acre plats was 71.3 bushels to the acre; on plastered plats the yield was 70.6 bushels, and in another experiment the increase through the use of plaster was one-tenth of a bushel.

CHAPTER XIII.

MISCELLANEOUS USES OF GYPSUM.

§ 1. Uncalcined Gypsum.

Gypsum in its ground uncalcined state is used as land plaster for fertilizer on various soils. Its value in this connection is much disputed and doubted, and the subject is discussed in the previous chapter. Commercial patent fertilizers have displaced this form to a very considerable extent. Many of these, however, have a base of gypsum to which are added the various other ingredients.

Terra Alba.

The white, finely ground, crude gypsum is sometimes sold under the name of terra alba for adulteration purposes. This substance is sometimes mixed with white lead paints, making a cheap substitute for the lead. It has been detected in flour, sugar, candy, baking powders, and other compounds. The pure food laws in a number of states have been instrumental in detecting a wide range of such illegitimate uses.

In India, powdered gypsum is kept in the bazaars as a drug. It is supposed to have cooling properties, and a gruel made from it is given in fevers. It is also used by the Chinese in a similar way. In India it is also calcined and used for chewing with betel, though sometimes carbonate of lime is used instead.

Gypsum is sometimes added to the water used in brewing. Soft water,[1] free from saline matter is not good for brewing purposes, so sodium chloride and gypsum are added. The English laws allow this to be added up to 50 grains per imperial gallon. Soft water gives higher extracts as it dissolves the albuminous matter in the malt more effectually than in hard water, but the impurities are powerful agents of change. Lower Michigan waters will rarely need gypsum added to them.[2]

The famous Burton ales in England are made with water from wells which pass through the gypseous deposits in the Keuper marls of the district. This water is considered especially desirable for brewing. Its composition is as follows, in an imperial gallon of 10 lbs.=70,000 grains:

[1]Encyclopedia Brittanica, Vol. IV, p. 275.
[2]See U. S. G. S. Water Supply. Paper No. 31.

	Grains.
Chloride of sodium	10.12
Sulphate of potassium	7.65
Sulphate of lime	18.96
Sulphate of magnesia	9.95
Carbonate of lime	15.51
Carbonate of magnesia	1.70
Carbonate of iron	0.60
Silicic acid	0.79
	65.28

In another large brewery at Burton, analysis shows the water to contain 54.5 grains of sulphates and 9.93 of carbonate of lime.

Gypsum flour or terra alba is mixed with poorer grades of wheat flour and used for dusting the moulds in metal casting. The mixture is sold under the name of Corine flour.

The crude gypsum is used in the preparation of some pharmaceutical preparations. It is also used in some methods of decomposing ammonia in the manufacture of sal-ammoniac.

Thin plates of selenite are sometimes used in optical work to determine the positive and negative character of minerals, and as it does not transmit heat well it is used to protect the lenses of optical lanterns.

Garnierite or the hydrous silicate of nickel, is mined in New Caledonia, and it is one of the important sources of nickel. The ore is smelted in a low blast furnace with coke and gypsum.

In Michigan, a special branch of manufacture is that of bug plaster, which is a land plaster mixed with Paris-green or other poison and used on potatoes and vines to destroy the insects. As a base of insecticides it is widely used.

Manufacture of Crayons.

Chalk crayons for blackboard and carpenter's use, are now commonly made from gypsum. The ground uncalcined gypsum is mixed with other ingredients according to a secret formula, pressed and dried and packed in boxes. One of the largest companies engaged in this work is the American Crayon Co., of Sandusky, Ohio, established in 1835. Their new works, completed in the fall of 1902, is the largest factory of this kind in the United States. They manufacture a variety of products besides crayons. The company sells annually about 18,000 cases of crayons, requiring 80 pounds of gypsum to the case, or 720 tons a year. The gypsum is obtained from the Marsh quarry at Port Clinton.

Hardening of Gypsum Blocks.

Various methods have been devised to harden blocks of gypsum to imitate marble. A Canadian company a few years ago quarried large blocks out of the Alabaster quarry with a channeling machine. These blocks were shipped to near Toronto and hardened, but for some reason the work was abandoned. Some of the Michigan gypsum has been hardened at Chicago, but the work has been on a small scale. A Chicago company a few years ago established a factory for making this artificial marble at Canyon City, Colorado.

A number of patents have been issued for this work. Patent number 549,151 (1894) by Mr. Geo. W. Parker, formerly of San Francisco, is entitled "Process of Treating Gypsum Rock to Imitate Chalcedony." The claim is as follows:

"The process of treating gypsum rock to represent chalcedony consits in first completely dehydrating the rock by the action of hot air, next allowing the now porous rock to absorb a solution of sulphate of iron, nitric acid, and potassium sulpho-cyanide, after which immersing in a solution of aluminum sulphate [$Al_2 (SO_4)_3$] for fifteen hours, next expose to air and then polish as set forth."

Patent number 588,287 (1897) by Geo. W. Parker of Grand Rapids, (filed October, 1895; renewed, July, 1897), is entitled "Gypsum Rock to Imitate Marble." The claim is:

"The process of treating gypsum rock which consists of eliminating the moisture from the rock by the action of hot air, then removing the then hot calcium sulphate into a closed compartment charged with the fumes of ammonia and then immediately immersing the cool rock in a warm solution of aluminum sulphate until the pores are filled, as set forth."

Hardened gypsum treated with stearic acid or with paraffine and polished, resembles meerschaum, and it is used for cheap pipes. Sometimes coloring solutions of gamboge are added to complete the resemblance.[1]

Use of Uncalcined Gypsum in Portland Cement.

A small amount of gypsum added to Portland cement, retards its set and apparently does not injure its tensile strength. Large amounts will retard the set of the cement and also give it a greater tensile strength, but after a time the set cement will begin to check.

In one briquette tested which had been mixed with a high percentage of gypsum, the tensile strength in 24 days was 1,100 pounds, with no trace of cracks or checks. This broken briquette is now over a year old,

[1] Wagner, Chemical Technology, p. 333, 1889.

and it is badly checked and cracks extend nearly half way through the block.

According to Michaelis,[1] gypsum may be added to cement in amount up to four per cent by weight to increase the hardness, though the German regulations and those of the London Chamber of Commerce permit but one-half of this amount.

This writer states that the gypsum in the cement takes the form of calcic aluminate, $Ca_3Al_2O_6+3\ CaSO_4+n\ H_2O$, the n probably equalling 30. This substance crystalizes in needle shaped rods of one-half millimeter in length. Most Portland cements have seven to nine per cent of alumina and can take up 28 to 36 per cent of calcic sulphate and water. If in larger quantities these crystals forming and expanding will break the cement.

The experiments of Candlot[2] show the following influence of gypsum on the cement. 100 grams of cement are used and the amounts of gypsum added as shown in the first column.

Grams of gypsum.	Initial set. Hours.	Minutes.	Final set. Hours.	Minutes.
0.0	0	7	0	22
0.5	0	50	2	40
1.0	2	40	4	50
1.5	2	57	5	17
2.0	3	00	5	20
3.0	3	00	6	40
4.0	3	30	7	00

According to Candlot, the time after the mixture is made has its effect on the setting of the cement. A mixture of cement with three per cent of gypsum showed the following variation with time:

	Initial set. Hours.	Minutes.	Final set. Hours.	Minutes.
On day of mixture	1	00	7	00
4 days after mixture	0	5	2	15
7 " " "	0	5	0	20
11 " " "	0	8	0	30
15 " " "	0	5	0	30
32 " " "	0	10	0	30
41 " " "	0	45	5	30

His explanation of the influence of the gypsum on the cement is that the gypsum combines with the aluminate of lime and loses all its water at 300° and forms a sulpho-aluminate of lime with the formula (Al_2O_3 3CaO) 2½ SO_3CaO). He states that in Portland cement there is always some free lime and very little alumina. As this free lime dissolves rapidly, it hinders the hydration of the alumina. The sulphate of lime added to the cement is not able to combine with the alumina and adds its action to that of the lime to hinder the hydration of the aluminate. The set is ascribed to the aluminate, and the gypsum hinders its hydration.

[1]The Cement Bacillus by Dr. Wilhelm Mi haelis, The Eng. Record, Volume 26, p. 110, 1902.
[2]Candlot, Ciments et Chaux Hydrauliques (Paris), p 325; 1898.

According to Dibdin[1] the gypsum is first dissolved and then precipitated in very fine particles on the grains of cement, so the chemical incorporation of the water in the cement is delayed. By some simultaneous occurrence of some chemical action the cement has greater strength.

The influence of gypsum on the strength of the cement is shown in the following table from Dibdin:

Breaking weight in pounds of briquettes of one square inch section after 28 days.

	No. 1.	No. 2.
With no gypsum	618	800
0.1 per cent gypsum	587	693
0.3 " " "	630	750
0.5 " " "	623	777
0.7 " " "	590	813
1.0 " " "	690	823
1.5 " " "	657	890
2.0 " " "	613	860

§ 2. Calcined Gypsum.

When gypsum is calcined it is known as plaster of Paris. The finer grades are sold as dental plaster and as plaster of Paris for the manufacture of casts and moulds. It is also used for white finish on the walls of buildings. Dental plaster is usually reground and carefully sifted so as to give a superfine plaster free from grit. Our museums of art show the large use of plaster for moulds and casts of ancient works of art and architecture.

Plaster was prepared at the old Phoenix Plaster Mill of New York city for glazing porcelain, a use which has apparently disappeared with time, other forms of glaze being regarded as better adapted to this work.

It has also been recommended by Prof. Moses of Columbia University, for use in place of charcoal in blow pipe tests.

§ 3. Wall Plaster.

In this country, gypsum wall plasters known under the names of rock wall plaster, hard plaster, cement plaster, adamant, etc., are either mixtures of plaster of Paris and retarder, or of plaster of Paris, retarder and sand. Such plasters set slowly and are applied to the walls in the same way as lime plasters.

Strength of Wall Plasters.

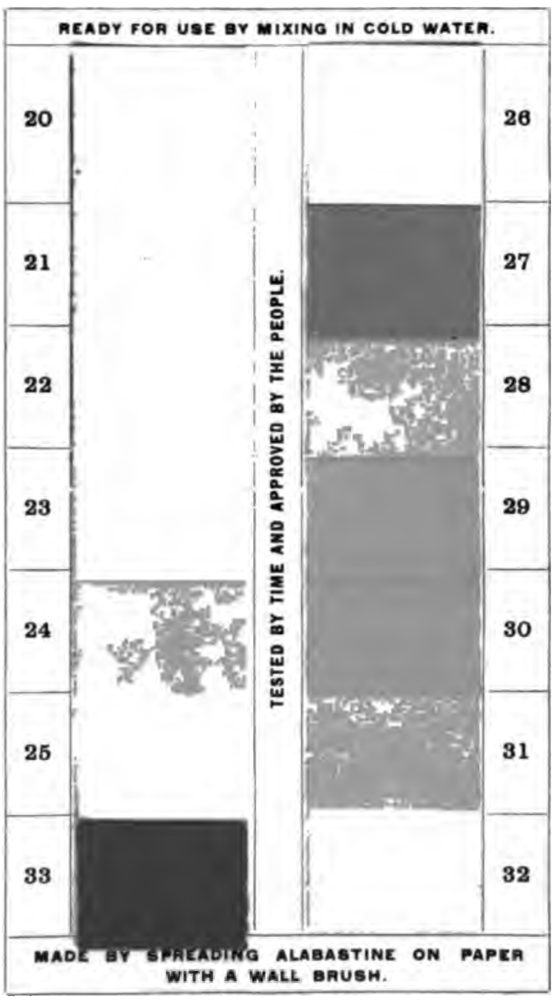
In determining the hardness and strength of wall plaster the French workmen are accustomed to ascribe the strength of the plaster to the hardness of the original gypsum rock. So that other conditions being equal, according to the French rule, the harder the gypsum rock, the stronger the plaster made from it.

[1] Lime, Mortar and Cement, by Dibdin (London), p. 128; 1868.

ALABASTINE

FOR WALL TINTING AND DECORATING

In Plain and Relief Work.



The Paris gypsum contains a high percentage of lime carbonate (12%), and it makes a plaster of high strength, but Gay Lussac pointed out that this was not due to the lime carbonate directly, as the lime carbonate was not altered at the temperature used in burning gypsum, but the lime still might add to the more equal distribution of the heat and help to avoid the danger of overburning.

The amount of water used in guaging the plaster is also important in determining the strength of the resulting product. To obtain all the strength of the plaster it is stiff gauged (gache serré) by adding very little water. In making the finish plaster more water is added than before the plaster is guaged thin (gache clair).

In the use of ordinary lime plaster three coats are usually applied to the wall. The first rough or scratch coat, composed of lime and sand, is applied to the wall or lath and dried in ten days to two weeks. It is common to scratch or furrow this coat with a trowel so that the second coat will adhere more firmly. The rough coat must be thoroughly dry before the second or brown coat is applied. In composition the second coat is practically the same as the first and dried in about the same time or a little longer.

The last or finish coat is applied after the second is thoroughly dry. It is made from slaked lime putty made two or three weeks before it is used, mixed with plaster of Paris, and pure white, fine sand, or from a mixture of plaster of Paris and lime putty. The workmen must then wait until the wall is thoroughly dry before the wood work can be nailed on the walls.

In working with gypsum plasters, the first or rough coat is applied and before it is set the second or brown coat is applied and thoroughly pressed into place with the first one. This makes practically one coat of plaster, three-fourths of an inch thick. The cement plaster for this work is mixed with two parts of sand. In 24 hours the last or finish coat, about one-eighth of an inch thick, is put on. It is composed of pure plaster of Paris and lime putty. In order to give a white smooth marble like surface, the brown coat is brought to a smooth surface, and the white coat is worked down with a flat wooden trowel called hand float, and a water brush to dampen the wall. When the walls are to be painted a sand finish is often used where sand is mixed with the final white coat so as to give a rough finish.

On account of the hard plasters setting more rapidly than the lime plasters, it is difficult for a workman familiar with lime work to float a hard plaster wall until he has become accustomed to its use. As a result lime plaster men with little experience with gypsum plasters nearly always condemn them.

The plaster is applied directly to the brick or stone wall, or it is spread over laths made of split white or yellow pine, three to four feet long, one

and one-half inches wide, and one-fourth inch thick. One-quarter inch space is left between the lath for the clinch of the plaster.

In fire proof buildings metallic lath are used, made of woven wire, or perforated metal, either plain or galvanized. Expanded metal lath has also become very popular and is regarded by many as superior to the other kinds. About 18,000,000 square yards of expanded metal lath are used each year in this country. Nearly 10,000,000 square yards were used in the construction of the buildings of the Paris Exposition, and most of this was furnished from the United States.

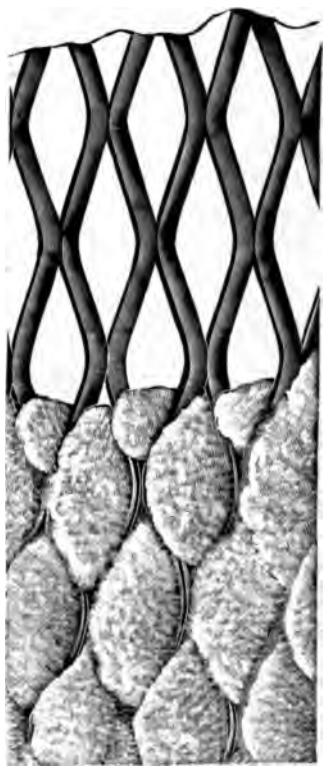


FIG. 44.

In making the expanded lath a strip of metal seven inches or more wide and eight feet long is placed upon a table and a cutter operates on it longitudinally cutting and expanding one row of webs at a time. The best types of these machines will make 400 to 600 yards a day. In a recent method invented by Mr. G. A. Turnbull of Chicago, a sheet of metal seven and one-half inches wide and of the desired length is fed into the rolls and cut in a number of short longitudinal overlapping slits. The sheet then passes over the expanding rolls, and the metal is stretched

out in width, enlarging the openings. The machine used in this method will make 4,000 to 5,000 yards a day.

The metal lath is fastened to the studding by iron staples, and the clinches formed in the numerous openings give increased firmness to the wall. There are numerous patent metal laths now placed on the market. Different builders prefer different makes and each thinks he has chosen the best. Where the plaster passes through the perforations it spreads out and forms a coat on the inside as well as on the outside of the metal, protecting it from rust, making strong clinches, almost impossible to break, and gives an almost perfect fire proof wall.

In Michigan most of the calcined gypsum is used for wall plaster, and its advantages as set forth in the advertising circulars of the companies and supported by the testimonials of prominent architects and builders are as follows:

Its superior tensile strength and hardness. It dries out much more rapidly than lime plaster, so that the carpenters can soon follow the plasterers; the painter and paper hangers can follow the carpenters in a day or two. The entire building can be delivered and occupied from five to six weeks sooner than with lime mortar. Coloring compounds can be mixed with the material in its preparation for mortar to produce any tint desired. Ceiling and walls thoroughly soaked from leaking and unprotected roofs have not been injured. It attains a high polish and may be used for wainscoting as a substitute for marble. It is fire proof and a non-conductor of heat and cold, so that changes of temperature do not affect the walls which therefore do not chip or crack. The walls being dense and hard are vermin proof, making the plaster valuable for hospital walls.

That these hard plasters are appreciated by the trade is seen from the following extract from the American Architect:

"In this age of improvement it seems strange that men should so long have been confined to the use of lime, sand, and hair, for making interior walls and ceilings, especially since walls so made have proved very weak and unsatisfactory, and many know from sad experience what destruction, annoyance and loss ensue, when, from some slight cause, its own weight or rottenness, down come ceilings about their ears with the inevitable result of damage, dust, and confusion."

The great objection to the use of cement plaster has been the greater expense. It has cost about one-fourth more than the ordinary lime plasters, but the greater advantages more than compensate the first expense. It is also said to be noisier, i. e., does not deaden the sound so well.

In some localities the careless methods of mixing the materials have caused bad results in the work and have caused hard wall plaster to be

looked upon with disfavor. Too much sand will make the sack of plaster cover more area, but it weakens it and the same result follows the mixing of the old set plasters in the boxes with the new material.

The directions for the use of these hard plasters are given as follows:

Use clean, sharp sand and mix thoroughly with the plaster before adding the water and do not mix more than can be used in one hour. The materials should be mixed in a water-tight box and should never be remixed after its set has commenced. The box and tools should be cleaned after each batch. Brick walls and porous substances should be thoroughly wet before applying the mortar, in order to reach the full strength of the materials. Floating should be done with the least possible amount of water, as soon as the material begins to stiffen and before it sets. In troweling the finish work use as little water as possible to prevent joinings and water streak showing. Use by measure two parts sand to one part of fibred plaster. Dry lath should be sprinkled one hour before plastering. For the hard white finish, mix one-half lime putty with one-half of fibred plaster. One ton of gypsum plaster will cover 225 to 250 yards of surface on wood lath set one-quarter of an inch apart, or will cover 225 yards on metal lath, or will float 400 yard.

The brands of these gypsum plasters made in Michigan are, Plasticon, Eagle, Acorn, Hudson River Mills, Green A, Eclipse, Granite, Ivory, Adamant, Diamond, Alabaster.

In many parts of the United States, especially east of the Mississippi river, the demand is for a plaster mixed with sand, ready to be mixed with water and applied to the walls. In Lower Michigan the two brands manufactured are the Adamant and Granite Wall Plaster. The sand is thoroughly dried in revolving cylinders or over specially constructed stoves, and mixed in Broughton mixers with retarder and plaster of Paris, and fiber.

Gypstone.

A high grade hard plaster is now made in Houghton for use in Upper Peninsula. The makers, the M. Van Orden Co., claim for it that the constituents are very carefully weighed, not measured, very thoroughly mixed, and are very uniform, and as a local sand is used in mixing, the freight on it is saved. A fat Ohio, so called fire clay, i. e., white clay, is used as spreader, and it will be seen by Sec. 6, of Chapter VIII, also affects the set.

Many Michigan coal underclays might be used for this purpose.

In order to show the fire-proof properties of hard wall plasters, the Rock Wall Plaster Co. of Columbus, Ohio, performed the following experiment in the presence of a party of city and state officials:—

Four frames were made out of two by four studding, 12 by 18 feet square, two of these were wood lathed, one steel lathed, and one covered

with sheet steel. All but the last were plastered, common lime plaster on one, rock wall plaster on the other two. These were laid on the fires in the boiler furnaces in the Board of Trade building.

In less than one and one-half minutes the steel covered frame was burning. In seven minutes the lime plastered lath were burning. In 29 minutes there was evidence that the heat had penetratd the rock plaster on the wood lath but it had not effected the wood covered with the steel lath. At the end of 40 minutes the rock plastered samples were removed and found to be charred but not in flames, while the other two samples were practically destroyed.

The testimony of fire marshals and owners of buildings plastered with gypsum plaster, seems to be practically unanimous as the protection of such plasters against the spread of fires in such buildings.

An objection to the use of hard plaster in residences has been that the density of the wall makes it a good conductor of sound from one room to another, where the partitions are made of the plaster. In order to correct this fault various forms of fibred plaster have been invented, known as wood fiber, fire pulp, etc. A common material for this purpose is wood fiber made on specially constructed machines, and the wood fiber is mixed with retarded plaster. One of the very popular pulp plasters is made by the Napoleon Pulp Plaster Co., of Napoleon, Ohio. It is a mixture of marl, gypsum, fire clay, wood pulp, and fiber, retarder, and lime carbonate. Machinery for this fiber is manufactured by the Wood Fiber Machinery Co. of Sandusky, Ohio.

The gypsum plasters are sometimes mixed with materials to add to the fire-proof qualities. Mixed with asbestos it has been used for plastering the inside of stove bowls. Calcined gypsum is mixed with finely ground cinders and poured between the iron joists in fireproof buildings. Temporary plates are placed above and below the joists giving a smooth under surface for the finishing coat of the ceiling of the lower stories, and a smooth upper surface on which the tile floor may be laid. The material is claimed to be thirty-five per cent lighter, of twenty-five per cent greater strength, and sixty per cent cheaper than tiling which has long been used for this purpose.

Plaster mixed with asbestos is said to give double strength. This mixture has been found valuable around steel beams in fireproof buildings. In such buildings a small fire doing but little apparent damage, will sometimes warp these beams and so twist the structure as to greatly injure its strength.

§ 4. Manufacture of Hardened Gypsum Plasters.

When gypsum stone is heated and thrown into a ten per cent solution of alum for a few minutes, and then heated again, the resulting plaster on setting is very much harder than the ordinary plaster.

Payen, as stated in the chapter on Technology, in his sixth principle, thought the hardening was due to the formation of a double sulphate of potash and lime. Landrin analyzed so called alum plasters with the following results:

LANDRIN'S ANALYSES OF ALUM PLASTERS.

Elements.	French cements.	English cements.		Stucco.
Carbonate of lime........	1.05	0.41	0.37	0.36
Silica	0.72	.....	0.42	0.51
Water	1.48	1.45	1.19	1.08
Sulphate of lime.........	96.75	98.19	98.02	98.55

An examination of these figures shows that the alum cements are of great purity, and there is no trace of alumina and potash. Landrin explains the hardening of alum plasters as due to the reaction of sulphate of alumina and potash on the plaster stone, converting nearly all the carbonate of lime into the sulphate, or gypsum. This seems to indicate that the French preference for lime plasters is prejudice.

Landrin placed the crude gypsum in a ten per cent solution of sulphuric acid for fifteen minutes and then calcined it, and obtained a plaster of good set and hardness. Heat must be applied in sufficient amount to drive out all the sulphuric acid and the best temperature was found to be between 600° and 700° F. Hydrochloric acid was also tried but with poor results.

By the Greenwood hardening process, the gypsum stone is burned in the usual way, then steeped in an 8% to 10% alum solution for some minutes, drained and dried in the air, and again burned at a uniform and constant temperature carried to dull redness but not beyond.

The earlier patents of Keene and later of Keating called for a mixture of plaster of Paris with one part borax, one part cream of tartar, and eighteen parts of water. This mixture was burned at a low red heat for six hours.

Borax alone produced good results. One volume of saturated solution of borax and twelve parts of water made a plaster which set in one-fourth hour; with eight volumes of water, it set in one hour; and with four volumes of water, the set was delayed several hours. This cement is known under the name of Parian cement. These cements were liable to effloresce, throwing off paint, and this is remedied by neutralizing the acids.

Keaur and Knop made silicated plaster used for sponging plaster casts, giving them increased hardness. To a potash lye made by adding one part potash to five parts water, some milk whey is added as free as possible of fatty matter. Four parts of this lye are mixed with a syrupy

solution of potassium silicate. Sulphur in the whey may make dark stains which will disappear when dry.

A German method of making a hard plaster is to add to plaster of Paris, two to four per cent of pulverized eibisch roots and mix with 40% water. This will harden in an hour. Eight per cent solution will make a still harder solution.

Martins' cement is a mixture of plaster of Paris and (commercial K_2CO_3) pearl ash, instead of borax, and produces a fatter cement. Kuhlman's method was to harden the plaster with a solution of water glass, but it is not always satisfactory. Blashfield used lime water to which some zinc sulphate is added.

Heinemann, in Hanover, under patent issued July, 1883, heated the crude gypsum rock and placed it in a lime chloride solution, then immersed it in a magnesia sulphate solution, and finally treated with lime and tannin solution, and dried the product. The finer varieties of white plaster are sometimes called Marezzo marble or white Portland cement.

Magaud's cement is made by treating the gypsum with a solution of sulphate of zinc, sulphate of iron, or sulphate of copper.

M. Julke communicated to the French Academy of Sciences in 1885 a new method for hardening plaster. By this method six parts of the best quality of gypsum plaster and one part of fat lime recently slaked and finely sifted are mixed. This is used in ordinary plaster. When it is dry the mass is soaked in a solution of some sulphate whose base may be precipitated by lime forming in insoluble precipitate. Among the most convenient sulphates are iron and zinc. The lime in the pores of the plaster decomposes the sulphate producing two insoluble bodies, sulphate of lime and oxide of lime which fill the pores giving the dense hard plaster. With zinc sulphate the object remains white, while with iron it is at first greenish and on drying it takes a reddish color. The iron surfaced casts have a strength twenty times greater than in the ordinary plaster casts.

Landrin found that lime had great influence in gypsum plasters. By mixing lime with the plasters in different proportions he obtained plaster which set regularly, became hard and took a high polish. He states that it is better not to use over ten per cent of lime. Landrin's explanation for this change is that the lime in contact with water sets free heat, which evaporates the quantity of water not needed to bring the hydrated plaster back to its original gypsum state. The carbonic acid of the air then carbonates, little by little, the excess of lime in the plaster, giving increased solidity and hardness to the plaster.

General Scott invented a mixture sold under the name of selenitic mortar which consists of Portland cement, with plaster of Paris or green copperas (ferrous sulphate). This hastened the set, and the invention attracted much attention some years ago, but modern experience is against this addition where great strength is required.

Scagliolia is a mixture of plaster of Paris, retarder, and coloring substances and is used to imitate various kinds of marble and ornamental stones. The original mixture contained numerous splinters (scagliole) of marble which has given the name.

In the Pantheon of Paris[1] the surface of the dome was dried by large braziers to remove all moisture. A mixture of one part yellow wax, three parts oil, in which one-tenth of the whole weight of litharge had been mixed before melting, was then applied at a temperature of 212° F. It was laid on with a brush until the stone would absorb no more. The paintings of M. Gros were then put on and have stood 20 years without trace of cracking or change on this plastered wall. A mixture of one part oil with one-tenth of its weight of litharge and two or three parts of resin is sometimes used in this way.

Roman cement, sometimes cited as a variety of gypsum cement was according to Parker's original English patents a hydraulic lime made from lime carbonate nodules found in clay.

§ 5. Gypsum Paints.

The finely ground gypsum is calcined and carefully bolted, then set with water in the form of oblong prisms. These after thoroughly drying in the open air, are reground and the resulting powder is sold as Michigan whiting, and used in a variety of ways. The true whiting used with linseed oil in the manufacture of putty is carbonate of lime, and the Michigan whiting has been tried as a substitute but does not work satisfactorily.

The Michigan whiting is used as paper filler. The bleached pulp in the manufacture of paper is drawn out in fine fibers on the beater rolls and is then loaded with some mineral material consisting usually of china clay or fine gypsum. When this is added in moderate quantity it closes up the pores of the fibers and enables the paper to take a better finish. It is used especially in writing and printing papers.

§ 6. Selenitic Lime.

Selenitic lime[2] or cement is an artificial mixture of gray chalk or other similar lime and a proportion of plaster of Paris. In one method lightly calcined gray chalk lime is reheated to bright redness in shallow kilns having perforated floors, under which are placed pots of sulphur. The heat igniting the sulphur produced fumes of sulphurous acid which rise and form a coating probably of sulphate.

In another the sulphuric acid is sprinkled on the calcined lime, or plaster of Paris is mixed with the ground lime. In one method four pounds of plaster of Paris is mixed in one half pail of water, to be added to one bushel lime in a mortar mixing mill, with sufficient water to make

[1] Burnett. Limes. Cements. Mortars, London, pp. 97-112: 1892.
[2] Heath. A Manual of Lime and Cement. London, pp. 29, 30.

CHICAGO PLANT OF THE ALABASTER COMPANY.

a creamy paste. These limes set rapidly and soon become hard but they are not commonly used, and cannot be used where they are exposed to the weather.

§ 7. Alabastine.

Alabastine, made at Grand Rapids, is often called cold water paint. In its preparation the pure blocks of gypsum rock are selected, ground, calcined, and then reground to the finest powder. This superfine gypsum flour is mixed with metallic colors and sold in packages to be used for tinting and frescoing interior walls. Five pounds of the material will cover fifty square yards of plain tinting on a smooth non-porus wall. It can be used over any solid surface, such as plaster, wood ceiling, brick, or canvass, and is applied with an ordinary wall brush. It does not flake or scale off, and hardens like the wall on which it is placed and so can be applied coat over coat.

In mixing the material two and one-half measures of Alabastine are added to one measure of cold water and stirred thoroughly and should be used within five hours. It is flowed on the wall heavily and brushed out to the proper thinness. It is claimed to cover 50 to 100% more surface than kalsomine made from lime and glue. It can be made in any tint or combination of tints to match carpets or draperies. Forty tints can be made from three colors, red, yellow, and blue, mixed with white alabastine. See Plate XXV.

The material is used with a free hand relief machine in making raised designs for borders of rooms in any variety of patterns. It can be used to imitate ivory, embossed leather, antique metal, tiling, etc. It is used in a pneumatic machine for whitening the interior walls of factories and warehouses.

§ 8. Lieno.

Another preparation of fine ground gypsum and metallic colors is made by the United States Gypsum Co., and sold under the name of Lieno, a word formed by reversing the letters of the inventor's name, Mr. O'Neil. This material is made in shades somewhat like Alabastine, and it is used in the same way for tinting walls. The company make a special feature of the use of Lieno for relief work. For this purpose two parts of the material are used with one part of warm water. It is sold in five pound packages, 100 pound drums, and 300 pound barrels.

For relief work the Lieno is put on the walls with a Lieno free hand relief machine made by the company and shown in Figure 45. This machine is made of brass, nickel plated, and has two cylinders for holding the mixture, so that the helper can be filling one while the operator is using the other. Pressure is applied by a ratchet and lever which forces the material through the tube. The machine should be held in the right

hand and steadied with the left. The tube should rest lightly against the surface and at an angle to allow the material to flow out. A series of tubes are prepared through which the substance flows to the surface producing the various widths and shapes of lines and scrolls. A variety of designs are made from a few principal patterns grouped together in different ways. After the designs are made on the wall, they may be colored for any tint desired, or the coloring material can be used in making the relief.

These gypsum paints are now used in all parts of the country and have become very popular for interior decorations. An artistic painter can make original designs, giving variety and harmony of color. The inexperienced can secure patterns and careful directions from the companies.

§ 9. Trippolite.

In the building markets of Vienna a new gypsum mixture has appeared in recent years under the name of Trippolite, which has a gray color and contains mainly calcined gypsum and four or five per cent of powdered carbon. Trippolite is said to have double the strength of ordinary plaster and to remain under water without disintegration and can be used as a hydraulic mortar. Two analyses of this substance are here given:[1]

	A.	B.
Sand	1.16	1.40
Soluble silica	.....	1.35
Sulphate of lime	74.98	74.90
Sulphate of magnesia	0.11	.....
Carbonate of lime	6.44	4.61
Carbonate of magnesia	1.84	4.15
Iron oxide	0.55	0.54
Alumina, potash, soda	trace	trace
Carbon	11.60	11.44
Water	3.00	2.86
	99.68	101.25

§ 10. Pottery Moulds.

Plaster of Paris is used for the manufacture of moulds for various pottery designs, and this method of making pottery is taking the place of hand turning. In many of our American potteries, jugs, vases, etc., are made in these moulds.

In England 30,000 to 40,000 tons of plaster are used for this purpose annually, especially in Staffordshire potteries, and gypsum rock is often called in that section the potter's stone.

These moulds are used on a jolly wheel made like an ordinary turner's wheel, but provided with a hollow head which can receive moulds of

[1] Handbuch der Chemischen Technologie. Bolley and Birnbaum. Band 6, p. 360; 1885.

various kinds. Each jolly wheel is provided with from 1,000 to 3,000 moulds. In a large pottery where a wheel is run all day on one kind of ware and each mould used twice, it would require 1,200 to 1,800 moulds for this one kind of pattern. The porous gypsum mould permits the evaporation of moisture from the clay while the surface of the ware is not exposed, thus avoiding any danger from strong drafts which are sometimes destructive in hand turned ware placed on open shelves.

§ 11. Plate Glass Polishing.

After the plates of heavy glass in the plate glass manufacture come from the kilns or leers, it is ground smooth under revolving brushes charged with emery flour. In order to hold the plate firmly and remove all strain, large circular tables $24\frac{1}{2}$ feet in diameter and eight to ten inches thick with a weight of 66,000 pounds are covered with a coat of plaster of Paris finely ground and free from all traces of grit. In this plaster the glass plates are imbedded. When the first side has been polished, the plaster is broken off at the edges and the plates removed. The table is then thoroughly cleaned and coated again with plaster and the smooth side of the plate imbedded, while the other side is polished.

In many factories the gypsum is calcined in kettles at the factory and the old set plaster is recalcined and mixed with the new for the first polishing, but for the second side new plaster must be used to avoid any danger of grit coming in contact with the polished surface.

It requires 2,200 pounds of plaster for 1,000 square feet of plate glass. The Michigan gypsum from Alabaster is held in high favor for this use on account of its purity, and most of the plaster used comes from this mine. In the plate glass factories of the United States, 40,000 tons of plaster are used annually.

At Saginaw is located a modern plate glass works with a capacity of 1,000,000 feet per year, and the Alabaster superfine plaster is used in the polishing of the plates.

§ 12. Plaster Relief Work.

A plaster industry which has been in existence from an early day came into special prominence at the World's Fair. The buildings at the Chicago fair were constructed on the outside of gypsum plaster and fiber, making a composition known as staff. Large quantities of gypsum plaster were consumed in the construction of these temporary buildings and ornaments. In the same way large quantities of this stuff were used at St. Louis for the fair buildings. Most of the staff plaster at Chicago came from Michigan, and most of the staff at St. Louis is shipped from this State.

Staff is especially adapted for decorative construction and remains in good condition for a considerable length of time in outside work, but

the elements of the air will in a few years cause it to disintegrate and crumble, if not protected by some water-proof covering.

The use for interior relief and art decorations has increased to a remarkable extent since the Chicago exposition. The group figures and mouldings in American theaters, public halls, and even private residences, are now made from staff.

In this manufacture, the design is modelled by the artist, in clay and then a mould is made of gelatin glue. A mixture of stearic acid and coal oil is used to oil the mould and prevent the cast from adhering. Into this mould is thrown a mixture of plaster of Paris and fiber, and finally on the outer surface pure plaster. The whole is worked into the mould with the fingers, or in large designs it is pressed into the proper form by means of a wooden die or scraper with its edge cut to the proper shape. The plaster is allowed to set and is then removed from the mould.

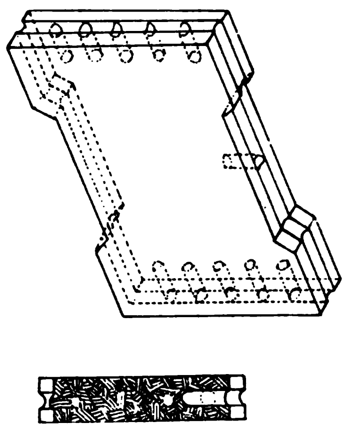


FIG. 45. Gypsum boards used in making walls where few uprights are used.

Large pieces are moulded over a steel frame which can be fastened in place by screws or staples. These designs are left in pure white or are painted in desired tints. Before painting they are coated with shellac. Large factories for this work are located in Detroit, Chicago, and other cities.

§ 13. Manufacture of Floor Blocks.

Gypsum plaster is sometimes mixed with sawdust and moulded into blocks which are then readily nailed to the wall for finish. The Mackolite Fire Proof Co., of Chicago, is engaged in the manufacture of fire-proof blocks for floors, walls, and ceilings, made from the Michigan plaster. The Grand Rapids Plaster Co., have recently started the manufacture of these boards.

The manufacture of these plaster building blocks for interior work is

a prominent feature in the German gypsum industry. (See Figures 45-46.) These boards or blocks ("schilfbretter") are described in detail in the Thonindustrie, page 1089, 1899. Another account is given by Mr. Wilder of the Iowa Geological Survey[1] report, from which source the following account is taken:

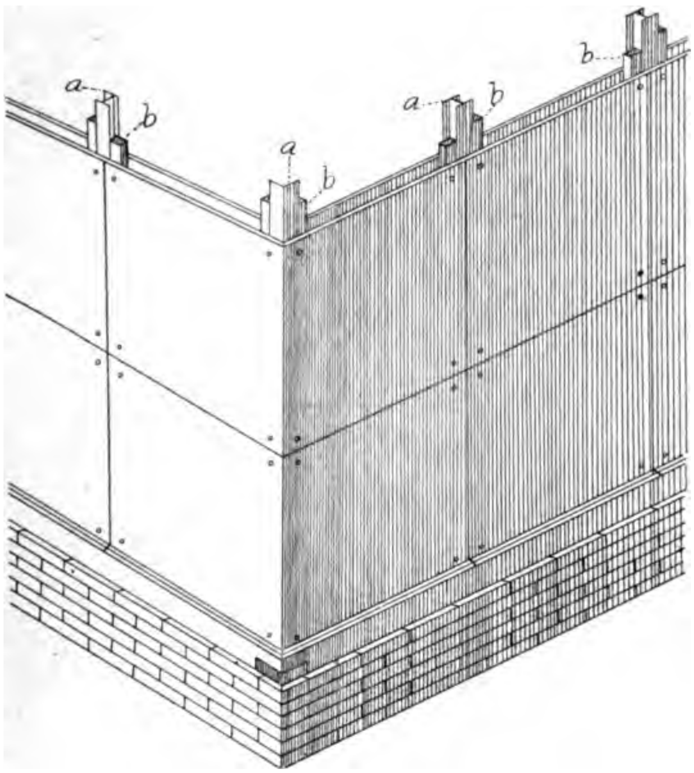


FIG. 46. Gypsum boards fastened to narrow wooden strips in iron uprights. Such a wall is practically fire proof.

"Calçined plaster is mixed with water and a certain amount of saw dust. On an iron table with a heavy iron top are laid iron strips, which have a thickness equal to that intended for the gypsum boards. The space enclosed by these strips also determines the length and breadth of the board. Within this space are scattered excelsior, jute, and rushes, and over these is poured the gypsum, water and sawdust mixture. The rushes and excelsior are carefully worked into the middle of the mass by hand. An iron bar is drawn over the top of the strips, leaving the surface of the mass either smooth or ridged. It is allowed to stand about five minutes, and then the iron table on which the mass rests is struck vigorously two or three times with a heavy mallet. This loosens the gypsum board from

[1]Vol. XII.

the iron plate and strips. A workman takes it on his shoulder and carries it to an open shed where it stands on end until dried by natural heat. The length of time required for drying depends wholly on the atmospheric conditions. Artificial heat for drying gypsum boards has proven very unsatisfactory, as the boards so dried crumble readily on exposure to the air. The weight of gypsum boards 2.5 centimeters thick is about 50 pounds per square meter, and for boards eight centimeters thick about 120 pounds."

§ 14. Gypsum as a Basis for Portland Cement, with Sulphuric Acid as a By-Product.

Attempts have been made to manufacture Portland cement and sulphuric acid from gypsum. It is claimed that the process will cost about the same as in the ordinary methods of making cement and there will be the sulphuric acid in addition for profit. One or two patents have been issued for this work, but the process has not gone much beyond the experimental stage.

Patent number 342,785 was issued in 1866 to Uriah Cummings of Buffalo, New York,[1] which gives the following method for this manufacture:

"In practicing my invention, I mix together gypsum or sulphate of lime and clay in the proportion of about 1,266 pounds of gypsum to 400 pounds of clay. I prefer to pulverize the gypsum and dry the clay and pulverize the same, then intimately mix the pulverized gypsum and clay and add a small quantity of water, and mould the mixture into blocks substantially in the manner practiced in making Portland cement from carbonate of lime and clay by the well known dry process. I then subject this mixture to calcination in a suitable kiln. At the high degree of heat which is maintained during the process of calcination the silicic acid contained in the clay expels the sulphuric acid contained in the sulphate of lime and combines with the lime and alumina and produces therewith silicates of lime and alumina, which, upon being reduced to powder, are in every particular a hydraulic or Portland cement. The sulphuric acid is expelled during this process of calcination either in the form of vapor, or it is decomposed and forms sulphurous acid and oxygen; or perhaps the escaping gas is a mixture of vaporized sulphuric acid, sulphurous acid and oxygen; according to the degree of heat which is maintained during the process of calcination, and which may vary somewhat at different times, owing to differences in quantity and quality of the fuel employed, strength of draft, etc. The gases escaping during the process of calcination are cooled in suitable chambers or passages lined with lead, in which the sulphuric acid is condensed and collected. The sulphurous acid, if any, is converted into sulphuric acid in the ordinary manner by means of steam and nitric acid. The sulphuric acid so obtained is then concentrated or further treated in any usual manner practiced in the manufacture of sulphuric acid. The mixture of gypsum and clay above specified produces about 711

[1]Iowa Geological Survey, Vol. XII, pp. 154-156.

pounds of hydraulic or Portland cement and 580 pounds of sulphuric acid from every 1,660 pounds of the mixture, the balance being moisture which is expelled. The cost of the sulphate of lime is about the same as that of the carbonate of lime and the cost of manufacturing hydraulic or Portland cement by this improved method is about the same as that of the old method in which carbonate of lime is employed; but the sulphuric acid which is obtained in my improved method is valuable, and the value which it represents materially reduces the cost of the cement.

"In practicing this invention, any suitable kiln in which the process of calcining can be carried out may be employed, and any ordinary apparatus may be used for recovering the sulphuric acid.

"The condensing and covering chambers are connected with the top of the kiln by a suitable flue, and the waste gases are discharged from the condensing or converting chambers by a stack or chimney or suitable fan which maintains the proper draft through the kiln and the chambers.

"The proportions herein specified are found to be well calculated to produce the desired results; but they may be varied in accordance with the nature of the gypsum rock and clay employed within certain limits without changing the general results. If the proportion of clay used be too great, the cement will be of an inferior quality but the sulphuric acid contained in the sulphate of lime will be driven off and recovered. If any excess of gypsum be used the lime contained therein is in excess of the true combining proportions with the silicic acid and the sulphuric acid will not be driven off and the resulting cement will be inferior in quality by reason of the presence of sulphate of lime, although a small percentage of the latter my be present without exerting any specially deleterious influence."

According to the method of P. Van Denberg of Buffalo, New York. under patent number 642,390, issued in 1900, sulphuric acid is made from gypsum by subjecting the gypsum to heat and electrolysis produced by an electric current within a furnace and applied to the material while molten. In the presence of an excess of free oxygen, sulphur oxide is formed which is hydrated later, yielding sulphuric acid.

APPENDIX A.

GYPSUM STATISTICS.

In order to show the importance of the gypsum industry in the world, and especially in the State of Michigan, the following tables are presented. The tables have been taken from the reports on Mineral Re-

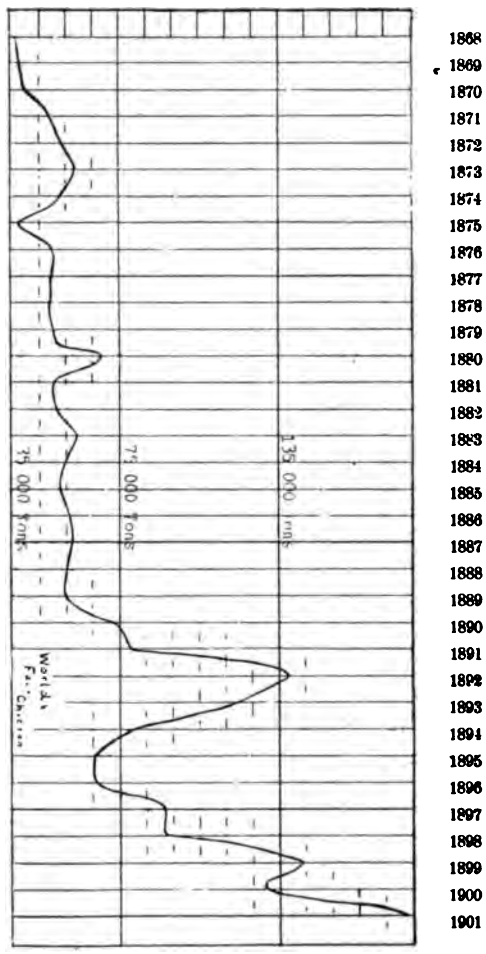


FIG 47. Total Production of Gypsum.

LIENO WALL DECORATIONS. (U. S. GYPSUM CO.)

sources published by the United States Geological Survey, and they are taken mainly from the 1901 report.

In the table of the Michigan production, the quantity of gypsum mined from 1867 to 1899 inclusive, is taken from Lawton's statistics as published in the government reports referred to above; but the amount of rock cal-

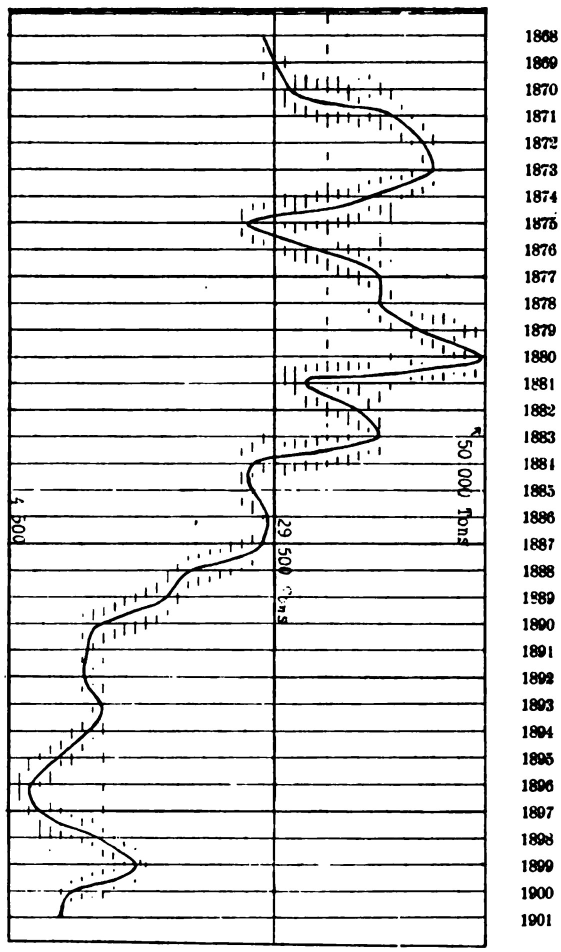


FIG. 48. Land Plaster Production.

cined into plaster, and the values were computed from these tables by the writer, taking estimated values for these years. The difference in the source of the statistics brings in a discrepancy between the values in 1889 and 1890.

A comparative study of these tables of statistics and of the diagrams accompanying them, brings out some interesting conclusions. From

table I, it is seen that France has held first rank in the production of gypsum in the world during the years 1893 to 1901, and the United States has held second rank. In 1894 France produced over six times as much gypsum as the United States, and in 1900 France only produced three times as much as the United States.

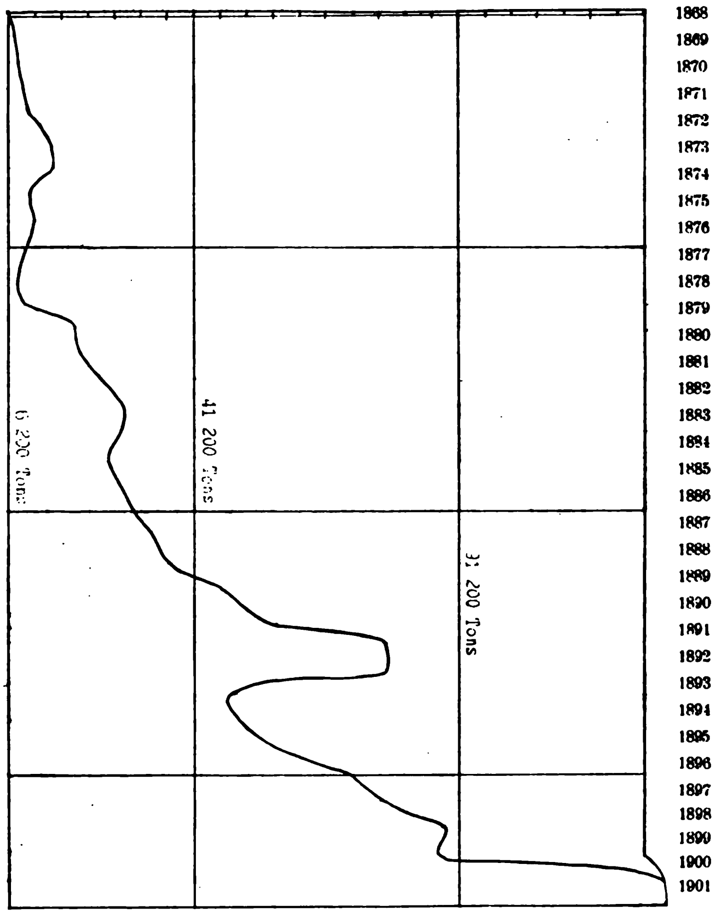


FIG. 49. Gypsum Calcined into Plaster.

Table III and Figure 47 show that the production of gypsum in the United States has increased in 20 years from 1880 to 1900 from 90,000 to 594,462 tons or 560 per cent. The production of gypsum in 1901 was the greatest recorded in the United States. The production in 1900 was the greatest recorded up to that year in the United States, Canada, Germany, Cyprus; but was less than the preceding year in Great Britian, Algeria, and India.

The imports of crude gypsum into the United States, which come al-

most entirely from Canada, were greater in 1901 than in any other year. The total amount of gypsum used in the United States in 1901, from these tables was 897,969 tons, with a value of $1,904,163.

In 1890, 56,525 tons of gypsum were ground into land plaster, and 107,728 tons were calcined, or about one-third used for land plaster, and two-thirds used for plaster of Paris and like products. In 1901, 65,698 tons were ground into land plaster, and 521,292 tons calcined, or about one-ninth used for land plaster, and eight-ninths for calcined plasters.

Michigan.

From the study of Table V, it is seen that the total production of gypsum in Michigan since the beginning of the industry is 2,827,793 tons, one-half of which was converted into land plaster and one-half into calcined plaster. Before 1868 about one-tenth of the product was calcined and nine-tenths was ground for land plaster.

In 1901, out of a total production of 185,150 tons, 129,256 tons were calcined or 69 per cent; and about 5 per cent was ground into land plaster, the remaining portion was sold crude.

The total value of gypsum quarried since beginning of the industry in Michigan is over $10,000,000.

A study of the diagrams, Figures 48 and 49, shows that production of calcined gypsum has steadily increased and the land plaster production has decreased. A marked increase in calcined plaster is shown in the years 1892 and 1893 during the World's Fair, the buildings of this exposition requiring large quantities of plaster in their construction.

TABLE I.

World's Production of Gypsum, from 1893 to 1902 inclusive.

	United States.		Great Britain.		Canada.	
Year.	Quantity, tons.	Value.	Quantity, tons.	Value.	Quantity, tons.	Value.
1893	253,615	$696,615	158,122	$287,940	192,567	$196,150
1894	239,312	761,719	169,102	321,822	223,631	202.031
1895	265,503	797,447	196,037	348,400	226,178	212,608
1896	224,254	573,344	213,028	361,509	207,032	178,061
1897	288,982	755,864	203,151	325.513	239,691	244.531
1898	291,638	755,280	219,549	345,882	219,256	230,440
1899	486,235	1,287.080	238,071	372,073	244,566	257.329
1900	594,462	1,627,203	233,002	348,210	252,001	259,009
1901	633,791	1,506,641	224,919	344,650	293,879	340,148
1902	816,478	2,089,341	251,615	....	332,045	356,317

TABLE I.—CONTINUED.

World's Production of Gypsum, from 1893 to 1902 inclusive.

Year.	France. Quantity, tons.	Value.	Algeria. Quantity, tons.	Value.	Germany. Quantity, tons.	Value.
1893	....	....	......	....	......	....
1894	1,693,831	$2,891,365	36,355	$114,900	......	....
1895	2,175,448	3,392,768	50,127	133,226	23,994	$11,040
1896	1,866,498	2,661,200	41,350	114,361	31,736	14,598
1897	1,845,874	2,673,033	40,510	109,648	28,821	13,228
1898	1,981,712	2,777,816	41,156	110,660	28,315	13,136
1899	1,802,812	2,641,020	44,037	117,895	32,760	19,660
1900	1,761,835	2,772,221	41,446	139,190	39,103	17,199
1901	2,182,229	3,449,747	38,955	132,286	35,013	23,139

Year.	India. Quantity, tons.	Value.	Cyprus. Quantity, tons.	Value.
1893	......	......	2,357	$6,625
1894	3,548	$1,566	3,104	9,006
1895	7,511	2,987	2,093	5,252
1896	8,248	3,130	1,050	2,590
1897	9,025	3,333	4,167	8,162
1898	9,249	1,503	4,279	7,551
1899	7,216	768	4,402	8,866
1900	4,865	424	......	......

TABLE II.

Gypsum Production in the United States since 1889, by States.

States.	1889 Tons.	(a) Value.	1890 Tons.	(a) Value.	1891 Tons.	(a) Value.	1892 Tons.	(a) Value.
Kansas	17,332	$94,235	20,250	$72,457	40,217	$161,322	46,016	$195,197
California	....	......	......	....	......	....	(d)	(d)
Colorado	7,700	28,940	4,580	22,050	......	....	(d)	(d)
Iowa	21,789	55,250	20,900	47,350	31,385	58,095	(d)	(d)
Michigan	131,767	573,740	74,877	192,099	97,700	223,725	139,557	306,527
New York	52,608	79,476	32,903	73,073	30,135	58,571	32,394	61,100
Ohio	(d)	(d)	(d)	(d)	(d)	(d)	(d)	(d)
South Dakota	320	2,650	2,900	7,750	3,615	9,618	......	....
Virginia	6,833	20,336	6,350	20,782	5,959	22,574	6,991	28,207
Other states (c)	29,420	109,491	20,235	138,942	17,115	94,146	31,301	104,461
Totals	267,769	$764,118	182,995	$574,523	208,126	$62,051	256,259	$695,482

States.	1893 Tons.	(a) Value.	1894 Tons.	(a) Value.	1895 Tons.	(b) Value.	1896 Tons.	(b) Value.
Kansas	43,631	$181,599	64,889	$301,884	71,852	$368,450	42,783	$199,563
California	(d)	(d)	(d)	(d)	5,158	51,014	1,310	12,580
Colorado	(d)	(d)	(d)	(d)	......	....	......	....
Iowa	21,447	55,538	17,906	44,700	18,600	43,710	18,631	34,020
Michigan	124 590	303,921	79,958	189,620	80,601	174,067	56,000	112,000
New York	37,126	65,392	31,798	60,262	29,176	50,806	22,923	39,771
Ohio	(d)	(d)	20,827	69,597	33,448	101,365	21,341	45,142
South Dakota	5,150	12,550	4,295	16,050	6,400	20,600	6,260	19,980
Texas	....	......	6,925	27,300	5,670	32,045	7,972	37,229
Virginia	7,014	24,359	8,106	24,431	8,515	32,068	5,444	18,210
Other states (c)	15,657	53,256	4,608	27,875	2,265	18,120	12,889	65,541
Totals	253,615	$696,615	239,312	$761,719	261,685	$892,245	195,553	$583,186

TABLE II.—CONTINUED.

Gypsum Production in the United States since 1889, by States.

States.	1897 (b) Tons.	Value.	1898 Quantity, short tons.	Value.	1898 Quantity, short tons.	Value.
California..........	2,200	$19,250	3,800	$24,977	2,950	$14,950
Colorado...........			5,390	23,712	0,675	24,954
Kansas.............	50,045	252,811	83,913	237,208	85,046	247,960
Iowa...............	65,000	195,000			75,574	296,220
Michigan...........	48,500	97,000	93,181	205,310	144,776	283,537
New York..........	22,885	40,253	31,655	81,969	52,149	105,533
Ohio...............	16,300	33,800	....	....	....	....
South Dakota.......	4 800	14,900	....	......	....	....
Texas..............	13,729	61,780	34,215	58,130	....	....
Virginia............	5,207	13,812	8,378	23,388	11,480	32,043
Other states........	13,195	91,071	31,106	101,586	108,585	282,153
Totals..........	241,861	$774,626	291,638	$755,280	486,235	$1,297,080

States.	1900 Quantity, short tons.	Value.	1901 Quantity, short tons.	Value.
California..............................	3,280	$10,088	3,550	$4,200
Colorado...............................	5,812	29,529	17,395	76,435
Kansas / Iowa	313,858	904,263	213,419	629,336
Michigan...............................	129,654	285,119	185,150	267,243
New York..............................	58,890	150,588	119,565	241,669
Ohio..................................	....	....	....	....
South Dakota..........................	....	....	....	....
Texas..................................	....	....	....	....
Virginia...............................	11,940	18,111	15,236	45,144
Other states............................	71,028	229,505	105,345	313,466
Totals.............................	594,462	$1,627,203	659,659	$1,577,493

TABLE III.

Production of Gypsum in the United States, by Years.

Year.	Quantity, tons.	Value.	Year.	Quantity, tons.	Value.
1902..........	816,478	$2,089.341			
1901..........	633,791	1,506,641	1890..........	182,995	$574,523
1900..........	594,462	1,627,203	1889..........	267,769	764,118
1899..........	486,235	1,287,080	1888..........	110,000	550,000
1898..........	291,638	755,280	1887..........	95,000	425,000
1887..........	286,982	755,280	1886..........	95,250	428,625
1896..........	224,254	573,344	1885..........	90,405	405,000
1895..........	265,593	797,447	1884..........	90,000	390,000
1894..........	239,312	761,719	1883..........	90,000	420,000
1893..........	253,615	666,615	1882..........	100,000	450,000
1892..........	256,259	695,492	1881..........	85,000	350,000
1891..........	208,126	628,051	1880..........	90,000	400,000

TABLE IV.

Gypsum imported into the United States form 1867 to 1902, inclusive.

Year ending June 30.	Calcined. Quantity, long tons.	Calcined. Value.	Unground. Quantity, long tons.	Unground. Value.	Value of Plaster of Paris.	Total Value.
1867	....	$29,895	97,951	$95,386	....	$125,281
1868	....	33,988	87,694	80,362	....	114,350
1869	....	52,238	137,039	133,430	$844	186,512
1870	....	46,872	107,237	100,416	1,432	148,720
1871	....	64,465	100,400	88,256	1,292	154,013
1872	....	66,418	95,339	99,902	2,553	168,873
1873	....	35,628	118,926	122,495	7,336	165,459
1874	....	36,410	123,717	130.172	4,319	170,901
1875	....	52.155	93,772	115,664	3,277	171,096
1876	....	47,588	139,713	127,084	4,398	179,070
1877	....	49,445	97,656	105,629	7,843	162,917
1878	....	33,496	89,239	100,102	6,989	140,587
1879	....	18,339	96,963	99,027	8,176	125,542
1880	....	17,074	120.327	120,642	12,693	150,409
1881	....	24,915	128,607	128,107	18,702	171.724
1882	5,737	53,478	128,382	127,067	20.377	200,922
1883	4,291	44,118	157,851	152,982	21,869	218,969
1884	4,996	42,904	166,310	168,000	......	210.904
1885	6,418	54.208	117,161	119,544	......	173,752
1886	5,911	37,642	122,270	115,696	......	153,338
1887	4,814	37,736	146,708	162,154	......	199,890
Dec. 31.						
1888	3,340	20,764	156,697	170,023	......	190,787
1889	5,466	40,291	170,965	179,849	......	220,140
1890	7,568	55,250	171,289	174,609	......	229,859
1891	9,560	97,316	110,257	129,003	......	226,319
1892	6,832	75,608	181,104	232.403	......	308,011
1893	3,363	31,670	164,300	190,254	......	211,924
1894	2,027	16,823	162,500	179,237	......	196,060
1895	3,295	21,526	192,549	215,705	10,352	247,583
1896	3,292	21,982	180,269	193,544	11,722	227,248
1897	2,664	17,028	163,201	178,686	16,715	212,429
1898	2,973	18,501	166,066	181,364	40,979	240,844
1899	3,265	19,250	196,579	220,603	58,073	297,926
1900	3,109	19,179	209,881	229.878	66,473	315,530
1901	3,106	19,627	235,204	238,440	68,603	326,670
1902	3.647	23,225	305,367	284,942	52,533	360,700

TABLE V.

Statistical table showing product on of gypsum in Michigan by years.

Year.	Land plaster, tons.	Gypsum calcined into plaster, tons.	Sold crude.	Total production, tons.	Total Value.
1902	13,022	158,320	68,885	240,227	459,621
1901	9,808	129,256	46,086	185,150	267,243
1900	10,354	86,972	33,328	129,654	285,119
1899	17,196	88,315	39,266	144,776	283,537
1898	13,345	77,852	1,984	93,181	204,310
1897	7,193	71,680	16,001	94,874	193,576
1896	6,582	60,352	700	67,634	146,424
1895	9,003	51,028	6,488	66,519	174,007
1894	11,982	47,976	20,000	79,958	189,620
1893	16,263	77,327	31,000	124,590	303,921
1892	14.458	77,599	47,500	139,557	306,527
1891	15,100	53,600	11,000	79,700	223,725
1890	12,714	47,163	15,000	74,877	192,099
1889	19,823	36,800	......	56,623	353,869
1888	22,177	35,125	......	57,302	347,531
1887	28,794	30,376	......	59,170	329,392
1886	29,373	27,370	......	56,748	308,094
1885	28,184	25,281	......	53.465	286,802
1884	27,888	27,959	......	55,847	335,382
1883	40,082	28,410	......	68,492	377,567
1882	37,821	24,136	......	61,957	34[illegible],374
1881	33,178	20,145	......	53,323	293,872
1880	49,570	18,929	......	68,499	349,710
1879	43,658	9,070	......	52,728	247,192
1878	40,000	8,634	......	48,634	229,070
1877	40,000	9,819	......	49,819	238,550
1876	39,131	11,498	......	50,629	248,504
1875	27,019	10,914	......	37,933	195,386
1874	39,126	14,723	......	53,849	274,284
1873	44,972	14,724	......	59,696	297,678
1872	43,536	10,673	......	54,209	259,524
1871	41,126	8,694	......	49,820	234,054
1870	31,437	8,246	......	39,683	191,718
1869	29,996	7,355	......	37,351	178,824
1868	28,837	6,244	......	35,081	165,298
Before. 1868	132,043	14,285	......	146,328	671,022
Total	1,035,795	1,436,850	336,238	2,827,793	$9,986,426

APPENDIX B.

BIBLIOGRAPHY OF REFERENCES.

LOCALITIES AND GENERAL PROPERTIES.

ÅNGSTRÖM—Memoire sur les Constantes Moléculaires des Cristaux du Système Monoclinoédrique; Memoires de l'Académie des Sciences de Stockholm, 1850; Extraits par M. Verdet in Annales de Chimie, 3rd series, Vol. XXXVIII, pp. 119-127: 1853.

ARKANSAS—Gypsum in; Arkansas Geological Survey, Vol. II, pp. 119, 241, 257: 1888.

ASIA MINOR—Gypsum in; Quart. Jour. Geol. Soc. Vol. V, p. 374.

BERZELIUS—Sur les proportions déterminés dans lesquelles se trouvent reunis les éléments de la nature inorganique; Annales de Chimie, 1st series, Vol. LXXVIII, pp. 33, 34: 1811.

BOOTH, M. L.—Marble Worker's Manual (Philadelphia).

BOYD—Resources of Southwest Virginia; pp. 104-108: 1881.

BRENNOFEN—Gyps-Brennofen von Hänschekc & Co.; Baugewerks Zeitung, Vol. XVI, p. 714.

BRENNOFEN—Gyps. by use of steam; Thonindustrie, Zeitung. Oct. 4, 1896.

BROCHANT—Observations sur des terrains de gypse ancien qui se rencontrent dans les Alpes et particulièrement sur ceux qui sont regardés comme primitifs; Extrait des Séances de l'Institut, in Annales de Chimie, 2nd series, I, p. 319: 1816.

BUFFALO, New York—Rock and Gypsum Deposits in Buffalo, by Pohlman; Proc. Amer. Inst. Min. Eng. (Buffalo Meeting): Oct. 1888.

BURNELL, GEO. R.—Limes, Cements, Mortars, etc. (London), pp. 97-112: 1892. Uber Pariser Gyps; Civil Engineer (London), p. 185: 1850.

CALCINING OF GYPSUM—Breschreibung des Dampf—Gypsbrennen—Apparats (Brennen durch Dampf von 6 Arm. Spannung); Thonindustrie, Vol. XX, p. 724. Chimie Appliquée a l'Art de L'Ingénieur, by Durand-Claye, 1897. Procédés et Materiaux de Construction, by A. Debauve, Vol. III, pp. 372-380: 1894.

Cuisson du plâtre, by Chatelier; Revue industrielle, Vol. XIV, p. 244; Comptes rendues, Vol. XCVI, p. 1668.

Lehrbuch der Kalk, Cement, Gyps, und Ziegelfabrikation, by Ruhne, pp. 53-60: 1877.

Handbuch der Chemischen Technologie.

Roret, Manuel du Chaufournier, Magnier; article Plâtre; pp. 272-312: 1881.

Formulæ, uses, etc. Die Kunst des Bildformers und Gipsgiessen, by Martin Weber (Weimar); 1886

Der Gipfer, by Hüttmann (Weimar).

LIENO WALL DECORATIONS. (U. S. GYPSUM CO.)

CALIFORNIA—Twelfth Report of State Mineralogist, pp. 323-325; 1894. Bull. 3, Cal. State Mining Bureau, p. 63: 1894.
The Gypsum and Cement Plaster Industry in California, by G. P. Grimsley; Eng. & Min. Journal, Vol. LXXI, p. 724: 1901.
CANADA—The Mineral Wealth of Canada, by Wilmott, pp. 105-111: 1897. Dawson's Acadian Geology.
Geology of Canada (Geol. Survey), 1863; pp. 347, 352, 459, 576, 762.
Mineral Resources of Ontario: 1890.
Production of Gypsum; Report S, Geol. Survey of Canada.
CANDLOT—Ciments et Chaux Hydrauliques (Paris): 1898.
CAPE BRETON—Gypsum in; Quart. Jour. Geol. Soc., I, pp. 211, 212, V, pp. 335-339; XLII, p. 523.
CEMENT BACILLUS—An account of the effect of gypsum on Portland cement, by Dr. W. Michaelis; London, Eng. Record, p. 110: July 6, 1892.
CHAMOUNIX VALLEY—Gypsum in; Quart. Jour. Geol. Soc., XI, p. 18
CHATELIER—Mécanisme de la prise du Plâtre; Comptes Rendu, Vol. XCVI, p. 715; Bull. Musée, Vol. LXXXIII, p. 108.
Cuisson du Plâtre; Revue industrielle. Vol. XIV, p. 244; Comptes Rendu, Vol. XCVI, p. 1668.
COLORADO—Gypsum in; Geology of Aspen Mining District; U. S. Geol. Survey, Mono. XXXI, pp. 239-241 (Spurr): 1898.
Gypsum and Clay in Colorado, by Arthur Lakes; Mines and Minerals, Dec. 1889.
Larimer County Gypsum, by Henry Lee; Stone, Vol. XXI, July, 1900.
COMPOSITION OF GYPSUM—Composition du Plâtre; Chronique industrielle, Vol. VI, p. 279.
DAUBRÉE—Mécanisme de la prise du Plâtre; Revue industrielle, Vol. XIV, p. 145.
DAVIES, D. C.—Earthy and Other Minerals and Mining (London), p. 105: 1890.
DIBDIN—Lime, Mortar, and Cement, London: 1898.
DIEULAFAIT—Produits successifs abandonnés par les eaux de la Mer; Annales de Chimie, 5th series, Vol. XIV, p. 381: 1878.
DUMESNIL OFEN—Zum Brennen des Gypses; Le Génie industriel, Vol. XXVIII, p. 315.
DURCISSEMENT DU PLATRE—Vie scientifique, Vol. II, pp. 273-274, 1898.
ECKEL—Gypsum in Virginia, U. S. G. S. Bull. 213, pp. 406-416: 1903.
EGYPT—Gypsum in; Quart. Jour. Geol. Soc., Vol. IV, p. 335. Transactions Amer. Institute Mining Eng., Vol. XI, p. 364.
EINHOF—Extrait d'un Mémoire sur la Vegétation; Annales de Chimie. 1st series, Vol. LV, p. 312.
ENGLAND—Official Blue Books of the Home Office, on Gypseous Deposits of Nottinghamshire and Derbyshire, by A. T. Metcalfe; Report British Assoc. (Nottingham meeting), p. 760: 1893.
Some Observations Upon Natural History of Gypsum, by J. G. Goodschild; Proc. Geol. Assoc., Vol. X, p. 425: 1889.
Thorpe's Dictionary of Applied Chemistry.

FLORIDA—Gypsum in (Bear Island); U. S. Geol. Survey, Vol. XX, part VI cont., pp. 662, 663: 1899.

FORMATION OF GYPSUM—Quart. Jour. Geol. Soc., Vol. V, pp. 172, 173, 339; Vol. VI, p. XLIX.

GARY—Die Gypsindustrie im Harz; Thonindustrie, Vol. XXIII, pp. 1079-1082: 1899.

Gypsbrennofen; Thonindustrie, Vol. XXII, p. 707: 1898.

GERMANY—Gypsum in; Die nutzbaren Mineralien und Gebirgsarten im Deutschen Reiche, by Dr. H. von Dichen (Berlin), pp. 731, 745: 1873.

Kalk, Gyps, Cement, by Tarnawski (Vienna), pp. 108-126: 1887.

Kalk, Gyps, Cement, by Böhmer und Neumann, pp. 137-165: 1886.

Prometheus, by Dr. Otto Witt (Berlin), numbers 583, 584: 1900.

The Gypsum Industry of Germany, by F. A. Wilder; Iowa Geol. Survey. Vol. XII, pp. 195-223: 1902. Eng. & Min. Jour., Vol. LXXIV, number 9, pp. 276-278: 1902.

GOULD, C. N.—Gypsum in Oklahoma, Second Bien. Report Okla. Geol. Survey, pp. 75-137: 1901-03.

GRIMSLEY, G. P.—The Gypsum and Cement Plaster Industry in California; Eng. & Min. Jour., Vol. LXXI, number 23, p. 724: 1901.

Gypsum Deposits of Kansas; Bull. Geol. Soc. America, Vol. VIII, pp. 227-240: 1897; American Geologist (abstract), Vol. XVIII, p. 237; Mineral Industry (New York), Vol. VI, p. 395; 1897; Trans. Kans. Acad. of Science, Vol. XV, pp. 122-127: 1896.

Technology of Gypsum; Mineral Industry, Vol. VII, p. 388-394: 1899.

Gypsum in Kansas; Univ. Geol. Survey, Vol. V, 183 pages and plates: 1899.

GYPSUM CEMENTS—Article Gyps, in Handbuch der Chemischen Technologie, Vol. VI, on Mörtel-Materialen, by Bolley: 1885.

GYPSDIELEN—By Mack; Dampf, Vol. X, p. 1063: 1893.

Baugewerkszeitung, Vol. XXV, p. 230.

GYPS UND SEINE VERWENDUNG—Handbuch für Bau, Maurermeister, Gipsgiesser, u. s. w., by Pedrotti (Leipzig): 1901.

GYPS IN DER ZUKUNFT—(feuerfesten Decken); Haaramanns Zeitung, Vol. XLIV, pp. 17, 18.

GYPSUM MILLS—By Lamoureux; La Génie industriel, Vol. XXV, p. 163.

In Paris—Zeitschrift für das Berg-Hütten und Salinen-Wesen in dem Preussischen Staate (Berlin); Vol. VI, p. 402.

GYPSUM KILNS (Gypsofen)—Description des machines et procédés consignés dans les brevets d'invention de perfectionnement et d'importation dont la durée est expiré et dans ceux dont la decheance a été prononcé publiée par les ordres de M. le Ministre de l'invention: Vol. XVII, p. 253; Vol. XXV, p. 378; Vol. XXVII, p. 320; Vol. XXIX, p. 166; Vol. XXX, pp. 12, 354, 357; Vol. XXXVII, p. 35; Vol. XXXVIII, p. 365; Vol. XL, p. 133;

Vol. XLVIII, p. 398; Vol. XLIX, p. 117; Vol. LIV, p. 42; Vol. LVII, p. 532; Vol. LX, p. 311; Vol. LXIII, p. 121.

System of Robert Uhler; Deutsche Töpfer und Zieglerzeitung, Vol. XII, p. 416.

Allgemeine Bauzeitung mit Abbildungen, pp. 229, 230 (1857); p. 334 (1865).

GYPSVERBÄNDE—(Entfernen durch Anfeuchten mit Essig); Pharmazeutische Centralhalle für Deutschland (Dresden), Vol. XL, p. 229.

HARDENING OF GYPSUM—Die verschiedenen Stadien in der Erhärtung des Gypses; Gewerbeblatt aus Württemberg, p. 298: 1875.

Härten des Gypses (mit Kieselsäure); Neuerste Erfindungen und Erfahrungen von Koller, Vol. XIX, p. 541.

Pharmazeutische Centralhalle für Deutsche, Vol. XLI, p. 576.

Gewerbeblatt aus Württemberg, Vol. LII, p. 76.

(of gypsum moulds); Apothekerzeitung (Berlin), Vol. XV, pp. 819. 820, Ber. Chem. Gesell., Vol. XVIII, p. 3314.

HARZ—Gypsum in; Quart. Jour. Geol. Soc., Vol. XI, p. 445.

Die Gypsindustrie im, by Gary; Thonindustrie, Vol. XXIII, pp. 1079, 1082: 1899.

HUDSON'S BAY TERR.—Gypsum; Amer. Inst. Min. Eng., Vol. XIV, p. 694.

HUNT, T. STERRY—Origin of Gypsum; Chemical and Geological Essays, Chap. VIII.

INDIA—Gypsum in; Manual of Geology of India, part 3 (Econ. Geol.), by Ball, pp. 450-454.

Mem. Geol. Soc. India, Vol. XI, p. 189; Vol. XVII, p. 195; Vol. XVIII, pp. 59, 93.

Trans. Bombay Geol. Soc., Vol. X, p. 229; 1852.

Jour. As. Soc. Bengal, Vol I, p. 289.

Natural Production of Burma, p. 31.

IOWA—Manufacture of plaster from Gypsum; Iowa Eng. Soc. Reports, Cedar Rapids Meeting, 1901.

Gypsum deposits in; Iowa Geol. Survey, Vol. III, pp. 260-304, by Chas. R. Keyes: 1895.

Gypsum deposits; Iowa Geol. Survey, Vol. XII, pp. 138-167, by F. A. Wilder: 1902.

Tests of Iowa gypsum; same report, pp. 224-235.

KANSAS—Gypsum deposits in; Univ. Geol. Survey, Vol. V, 183 pages, by G. P. Grimsley: 1899.

KILNS, GYPSUM—(See Gypsofen.)

KIRWAN—Suite du Mémoire sur la force des Acides et sur la proportion des substances qui composent les sels neutres (translated from English); De la Sélénite vitriolique ou sulphate de chaux; Annalas de Chimie, Vol. XIV, p. 244: 1792.

KOSMANN—Die Natur des Gypses und seine Verwendung zu Kunstmarmor; Thonindustrie Zeitung, Vol. XVI, p. 531 ff; Polytechinisches Central blatt, Vol. IV, p. 210.

Ueber das Abbinden und Abhärten des Gypses; Thonindustrie Zeitung, Vol. XIX, p. 29: 1895.

Uber die genetische Beziehungen zwischen Gyps und Anhydrit; Thonindustrie, Vol. XX, p. 906: 1896.

LACROIX—Formation d'Anhydrite par calcination du Gypse à haute température; Comptes Rendues, Vol. CXXXVI, pp. 533, 554.

LANDRIN—Die verschiedenen Stadien in der Erhärtung des Gypse; Gewerbeblatt aus Württemberg, p. 298: 1875.

Récherches sur la cuisson du Plâtre sur sa prise et sur les causes qui l'activent ou la relentissent: nouveau procédé de fabrication des stucs ou Plâtres dits alunes—ciments a base de plâtre et de chaux; Annales de Chimie, 5th. series, Vol. III, pp. 433-454; 1847; Academie des Sciences (Comptes Rendu) 1874.

LAVOISIER—Academie des Sciences; February 27, 1765.

Härten des Gypses; Deutsche Töpfer und Zieg. Zeit, Vol. XIV, p. 151.

LEE, HARRY—Gypsum in Larimer County, Colorado; Stone, Vol. XXI, July, 1900.

LEVALLOIS—Über Gypsofen in St. Leger d'Heune; Annales des Mines, series 1, Vol. VII, p. 403.

MACK—Fabrication de corps en plâtre hydraulique a prise rapide, (Beschleunigung des Erhärtens durch Zusatz von Kalisalzen); Moniteur de la céramique (Paris), Vol. XXVII, p. 171: 1896.

Gypsdielen; Dampf, Vol. X, p. 1063: 1893; Baugewerkszeitung, Vol. XXV, p. 230.

MALAGA—Gypsum in the Trias of; Quart. Jour. Geol. Soc., Vol. XV, pp. 592, 604.

MANCEAU—Matières organiques en présence de sulfate de chaux; Journal de Pharmacie et de Chimie, Vol. XXIX. p. 98: 1894.

MANIITOBA—Gypsum in; Canadian Record of Science, Vol. III, p. 353; 1889.

MARBLE ARTIFICIAL—(See also Kosmann.)

By Packer, Nouveau traitement du gypse pour produire du marbre artificiel, et autresm atières analogues (Trocken, Färben, Behandlen mit Ammoniak dämpfen und aluminum sulfat); Moniteur de la céramique, Vol. XXVIII, p. 207: 1897.

MARCY—Exploration of Red River (Texas) pp. 52, 91, 172, 173: 1852-3.

MARIGNAC—On the solubility of gypsum; Annales de Chimie, 5th series, Vol. I, p. 274.

McCALEB—On the solubility of gypsum; Amer. Chem. Jour., Vol. II, p. 30: 1889.

MICHIGAN—Gypsum in; Winchell Report for 1860, Michigan Geol. Survey, Vol. III, p. 102: 1873-76; Vol. V, pt. 2, pp. 91-98

Geol. Survey Annual, Report for 1901, pp. 15-18, by W. M. Gregory.

Mineral Statistics of Mich., pp. 3-20: 1881. Vol. VII, Parts I and II, passim.

NEW MEXICO—The gypsum plains; U. S. Geol. Survey, 12th Annual Report, part II, p. 281-282.

NEW YORK—Gypsum deposits of; Bull. New York State Museum, Vol. III, No. 15, p. 550, by F. J. H. Merrill: 1895. (Brief note with names of producers.)

Gypsum industry of; Bull. of same, Vol. III, No. 11, pp. 70-84, (with map), by W. C. Clark: 1893.

Gypsum deposits in Cayuga county, by S. G. Williams; Amer. Jour. Science, Vol. CXXX, p. 212.

Age of the gypsum deposits; by S. G. Williams; Amer. Jour. of Science; Sept. 1885.

Origin of gypsum deposits; Dana, Manual of Geology, p. 554: 1895.

Recent developments in the gypsum industry in New York state, by Arthur L. Parsons; New York State Museum, 20th report of State Geol., pp. 177-183: 1900.

NORTHWEST TERR.—Gypsum in; Geol. Survey of Canada, Vol. XXX D, CI, D.

NOVA SCOTIA—Gypsum in; Canadian Mining Review: March, 1896.

Gypsiferous formation of; Quart. Jour. Geol. Sec., Vol. I, pp. 26-35; Vol. V, pp. 26, 27, 129; Vol. VIII, pp. 398, 399.

Origin of the gypsum of Plaister Cove; Quart. Jour. Geol. Soc., Vol. V, p. 339.

OCHSENIUS—On the composition of sea water; Chem. Zeitung, Vol. II, No. 56 et seq.: 1887.

OHIO—Gypsum deposits in; Geol. Survey of Ohio, Vol. II, p. 135, by Newberry.

Gypsum or land plaster in Ohio, by Edw. Orton, Vol. VI, pp. 696-702: 1888.

OKLAHOMA—Gypsum in; 2nd. Biennial Report Depart. Geol. and Natural History, pp. 75-137, by C. N. Gould: 1901-02.

PARIS GYPSUM—LaCroix; Paris Museum Reports: 1897.

La Grande Encyclopédie; Article Plâtre; Vol. XXVI, p. 1078.

Lapparent, Géologie, pp. 135, 320, 321, 336-338, 692, 988, 993, 1026, 1035, 1039, 1474.

Le gypse de Paris et les minéraux qui l'accompagnent; nouvelles archives du museum, Vol. IX, (Paris) pp.201-296, 8 plates, by A. Lacroix: 1897.

Nouveau Dictionnaire des Sciences et de leurs Applications (Paris), pp. 498, 499: 1900.

On the peculiar and distributive characters of the gypsum found near Paris, and its preparation and application as a plaster, by Geo. R. Burnell; The Civil Engineer and Architect's Journal (London), Vol. XIII, p. 185-189: 1850.

PAYEN—Traité de Chimie Industrielle: 1830.

Uber Gypsbrennen; Bull. des Sciences technologiques, Vol. XIII, p. 246.

PENNSYLVANIA—Gypsum in; Geol. Survey of Penn., Summary Final Report, Vol. II, pp. 913-915: 1892.

PERIN—Dosage des incruits et des surcuits dans le Plâtre de Paris des fours culeés; Comptes Rendu, Vol. CXXXI, pp. 950-952: 1900.

PFAFF—Sur les boracites et le succin qui se trouvent dans le gypse de Segeberg (Holstein); Annales de Chimie, Vol LXXXIX, p. 199: 1814.

PLASTER ANCIENT—Ein plastischen Gypsmortel aus alter Zeit., Haarmann's Zeitung, Vol. XLIV, pp. 62, 63.

PLASTER OF PARIS—On the improved mode of making plaster of Paris (translated from Dictionnairie Technologique); Journal of Franklin Institute, Vol X, pp. 262-264: 1830.

PLASTERING METHODS, ETC.—American Builder, Sept. 18, 1897; Jan. 23, 1897. American Architect, Aug., 1896.

Canadian Architect, Feb., 1899.
Plain and decorative plastering, by Wm. Millar (London), 604 pages: 1897.
PLASTER OF PARIS—Method of calcining and boiling of plaster of Paris; Grand Rapids Democrat, Michigan, Nov. 6, 1892.
Manufacture of; Ecl. Eng., Vol. V, p. 423.
Scientific American Suppl., Vol. XXXI, p. 12, 685.
Scientific American (new series), Vol. XXIX, p. 399.
PORTLAND CEMENT—Use of gypsum in; Ciments et Chaux hydrauliques (Paris), by Candlot, pp. 325-335: 1898.
PORTO RICO—Gypsum in; U. S. Geol. Survey, 20th Annual Report, part VI Cont., p. 744: 1899.
PRODUCTION OF GYPSUM—In Oil, Paint & Drug Reporter, Vol. LVI, p. 26, (quotation from U. S. Geol. Survey Reports).
See the various reports on Mineral Statistics, in the volumes of the U. S. Geol. Survey Reports.
RED RIVER—(Of Louisiana, Texas); Marcy's Exploration; see Marcy.
REDGRAVE—Calcareous Cements, their nature and uses: 1895.
ROSE, H.—On the solubility of gypsum; Poggendorff Annalen, Vol. XCIII, p. 606.
ROSOY—Le Plâtre; Gazette des Architectes, Vol. XIX, p. 195.
SELENITIC LIMES—An account of the influence of gypsum on hydraulic limes; Van Nostrand Eng. Magazine, Vol. VII, p. 542.
A Manual of Lime and Cement, by Heath (London), pp. 29, 30.
SET OF PLASTER—Méchanisme de la prise du plâtre, by Chatelier; Comptes Rendu, Vol. XCVI, p. 715; Bull. Musée, (Paris), Vol. LXXXIII, p. 108.
Méchanisme de la prise du plâtre, by Daubrée; Revue industrielle, Vol. XIV, p. 145.
SHERWIN—Theories of origin of gypsum; Trans. Kans. Acad. Science, Vol. XVIII, pp. 85-88: 1903.
SOCQUET—Des éfflorescences de sulfate de Magnésie observées sur les Carrières de Montmartre; Annales de Chimie (2nd series), Vol. XLII, pp. 51-64.
SOLUBILITY OF GYPSUM—Amer. Chem. Jour., Vol. II, p. 30, by McCaleb: 1889.
Berichte des Deutsch. Chem. Gesellschaft, p. 330: 1877.
Jahresbericht der Chem. Technologie, by Wagner, p. 727: 1877.
In aqueous solutions of sodium chloride, by Dr. Frank Cameron; Journal of Physical Chem., Vol. V, pp. 556-576: 1901.
Lecoq de Boisbaudran, note sur la solubilité du gypse dans l'eau; Annales de Chimie (series 5), Vol. II, p. 477.
H. Rose; Poggendorff Annalen, Vol. XCIII, p. 606.
Löslichkeit von Gyps in Wasser; Zeitschrift fur Chemie, p. 735: 1867.
Solubility of gypsum in aqueous solutions of certain electrolytes, by Cameron and Seidell; Jour. of Phys. Chem., Vol. V, number 9, pp. 643-655: 1901.
Storer, Dictionary of Solubilities.
SOUTH AMERICA—Geology of South America, by Darwin (see article in index).

SOUTH DAKOTA—Gypsum in, and analysis of Hot Springs gypsum; U. S. Geological Survey Annual Report, Vol. XXI, part IV, p. 585.

SPERENBERG—Gypsindustrie in; Haarman's Zeitschrift fur Bauhandwerker (Halle), Vol. XLIII, pp. 11, 12.

STEVENSON—Gypsum in Holston Valley, Virginia; Proc. Amer. Philos. Soc. XXII, pp. 154-161: 1884.

STORER—Determination of water and sulphuric acid in gypsum; Chemical News, Vol. XXII, p. 99.

STUCCO—Ecl. Eng., Vol. XVI, p. 368.

SUGAR—Effect on cement; Engineering News, Dec. 24, 1887.

TESTS, PHYSICAL ON GYPSUM—Iowa Geol. Survey, Vol. XII, pp. 224-235, by Marston: 1902.

In Wyoming, by Slosson 10th Annual Report of Univ. of Wyoming, pp. 9-17: 1900.

TEXAS—Geological Survey of Texas, 1st. Annual Report, pp. 19, 30, 42, 43, 44, 46, 48, 52, 53, 73, 99, 100, 123, 188, 189, 193, 197, 205: 1889.

Second Annual Report, pp. 410, 447, 457, 458, 459, 700.

THORPE—A Dictionary of Applied Chemistry, Vol. 1, article on Cements.

THURINGIAN FOREST—Gypsum in; Quart. Jour. Geol. Soc., Vol. XI, p. 425.

TRIPPOLITE — Borchert, Illustrirte Zeitung für Blechindustrie; Deutsche Topfer und Zeiglerzeitung, Vol. XIV, p. 322.

Kalk, Gyps, und Portland Cement, Tarnawski (Vienna), p. 108: 1887.

TUSCANY—Gypsum in; Quart. Jour. Geol. Soc., Vol. I, pp. 280, et seq.: 1884.

UNITED STATES GYPSUM DEPOSITS—Bull. U. S. Geol. Survey, Bull. 223: 1904.

VIRGINIA—Resources of Southwest Virginia, by Boyd, pp. 104-108: 1881; U. S. Geol. Survey, Bull. 213, pp. 406-416: 1903.

In Holston Valley; Trans. Am. Inst. Min. Eng., Vol. V, p. 91; Vol. XXI, p. 28; Proc. Amer. Philos. Soc., Vol. XXII, pp. 154-161: 1884.

In Mesozoic; Trans. Am. Inst. Min. Eng., Vol. VI, p. 244.

WILDER, FRANK A.—On gypsum deposits in Iowa; Iowa Geol. Survey, Vol. XII, pp. 195-223: 1902.

The gypsum industry of Germany; same report, pp. 195-223.

Present and future of American gypsum industry; Eng. & Min. Journal, Vol. LXXIV, number 9, pp. 276-278: 1902.

WEBER, MARTIN—Die Kunst des Bildformers und Gipsgiessers: 1896.

WILKINSON—The technology of cement plaster; Trans. Am. Inst. Min. Eng.; July, 1897.

WILLIAMS—See New York gypsum deposits.

WYOMING—The Laramie cement plaster industry, by Slosson and Moody; Tenth Annual Report of Univ. of Wyoming, pp. 1-17: 1900.

ZULKOWSKI—Das Erharten des gypses; Thonindustrie, Vol. XXIII, pp. 1250-1252: 1899.

GYPSUM AS A FERTILIZER.

See also ante p. 193.

AIKMAN—Manures and Manuring (London), pp. 462-464: 1894.

BOSC—Royal Central Agricult. Soc. of France (vol. and page not found); sums up all information on the subject of gypsum as a fertilizer.

BOUSSINGAULT—Rural Economy.

BROWNE, D. J.—American Muck Book, pp. 68-75: 1851.

BUEL—Farmer's Instructor.

CHAPTAL—Chemistry Applied to Agriculture.

CHUARD—Etude sur le Plâtre; Journal de la Societe d'Agriculture, de la Suisse Romande, Vol. XXXII, No. 8, pp. 141-157 Lausanne: 1891.

Fumure des Vignes avec le sulfate de chaux; Chronique agricole du Canton de Vaud, p. 75: 1895, and in other numbers.

DAVY—Agricultural Chemistry, about 1814.

Gypsum as a fertilizer; Edinburgh Review, Vol. XXII, p. 279.

FERTILIZERS—Value of gypsum in its action on insoluble potash in the soil, by Edw. Voorhees, p. 116, 1898.

Importance of gypsum as manure; Quart. Review (London), Vol. XXIII, pp. 378, 379: 1820.

Facts and Observations respecting Canada and U. S., by Grece; (discusses the subject of gypsum).

Sir. H. Davy on gypsum fertilizers; Edinburgh Review, Vol. XXII, p. 279: 1814.

GYPSUM AS A MANURE—Experiments of Mr. Harbe; Agric. Soc. of Eng., Vol. III, p. 234: 1842.

The Gardeners' Chronicle and Agricultural Gazette (London), p. 858, 1844; p. 785, 1841; pp. 387, 388: 1864.

Manures and the principles of Manuring, by Aikman (London): 1894.

HARRIS—Talks on Manures, p. 204: 1878.

JOHNSON, C. W.—An account of gypsum as a manure to the artificial grasses (prize essay); Proceedings of Royal Agricultural Society of England, Vol. II: 1841.

JOHNSTON—Manures, pp. 177, 178: 1895.

Use of lime in Agriculture, pp. 204 ff: 1849.

KING—The Soils, pp. 177, 178: 1895.

LIEBIG—Chemistry of Agriculture.

MARVEL, IK—(Donald Mitchell), My Farm of Edgewood.

MASSEY, W. F.—Crop Growing and Crop Feeding, July, 1901.

PARKINSON—Practical Observations on Gypsum as a Manure.

ROBERTS—The Fertility of the Land, p. 254: 1897.

RUFFIN, EDMUND—Calcareous Manures (first written in 1832) pp. 147, 154: 1852.

SNYDER—The Chemistry of Soils and Fertilizers, p. 161: 1899.

STEPHENS, HENRY—The Book of the Farm, Vol. II, pp. 423, 424: 1855.

STOCKHARDT—The Familiar Exposition of the Chemistry of Agriculture, p. 226: 1855.

STORER—Chemistry of Agriculture, Vol. I, pp. 206, 216: 1887.
THIBAUT—Anwendung des Gypses als Düngen; Annales des Mines, series 3, Vol. VI, p. 193.
TURNER—Elements of Chemistry.
VIRGINIA—Resources of Southwest Virginia, by Boyd, p. 106.
VOORHEES—Fertilizers, pp. 115, 116: 1898.
WILEY—Principles and Practice of Agricultural Analysis, Vol. II, pp. 307, 307: 1895.
WILSON—Rural Encyclopedia, Vol. II, article on Fertilizers: 1850.

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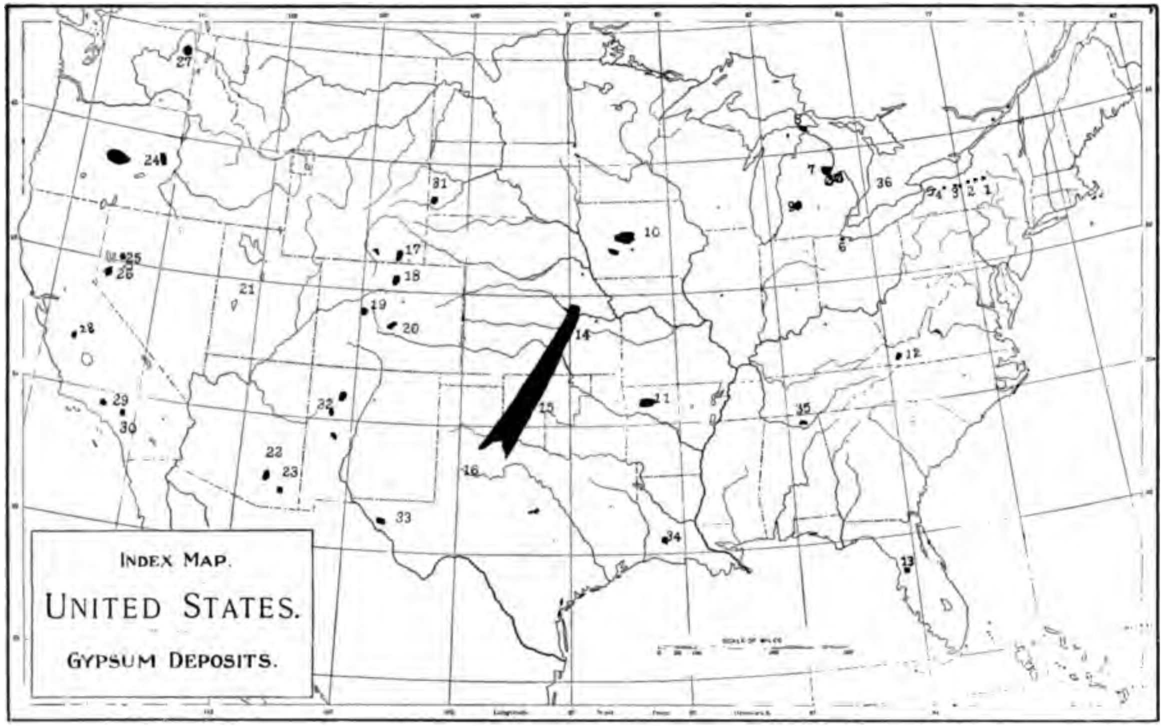

KEY.

1. Fayetteville, New York.
2. Union Springs, New York.
3. Mumford, New York.
4. Oakfield, New York.
5. Buffalo, New York.
6. Port Clinton, Ohio.
7. Alabaster, Mich.
8. St. Ignace, Mich.
9. Grand Rapids, Mich.
10. Ft. Dodge, Iowa.
11. Plaster Bluffs, Ark.
12. Smyth County, Va.
13. Bear Island, Fla.
14. Blue Rapids, Medicine Lodge, Kans.
15. Oklahoma.
16. Quanah, Texas.
17. Laramie, Wyoming.
18. Loveland, Colorado.
19. Aspen, Colorado.
20. Canyon City, Colorado.
21. Juab, etc., Utah.
22. Tucson, Arizona.
23. Santa Rita, Arizona.
24. Huntington, Oregon.
25. Lovelock, Nevada.
26. Empire, Nevada.
27. Washington.
28. Coalinga, Cal.
29. Los Angeles, Cal.
30. Riverside, Cal.
31. Black Hills, Dakota.
32. New Mexico.
33. Rio Grande, Texas.
34. Lake Charles, La.
35. Scotsborough, Alabama.
36. Paris-Cayuga, Canada.
37. Huron County, Mich.